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OXYGEN IN FEED AND BOILER WATERS.

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It seems anomalous that oxygen, which is a necessity to combustion on the fire side of a boiler, is a distinct enemy on the water side. Many tests have shown that oxygen is one of the preponderant factors in underwater corrosion processes. The behavior of oxygen in water and its absorption by water are of considerable interest. This paper presents some information collected in connection with an investigation of boiler feed water treatment at the U. S. Naval Engineering Experiment Station.

A study was made of the rapidity of absorption of oxygen by water in a quiescent condition in various containers and also while water was in circulation in a small simulative feed and condenser

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system. In addition to this, data was collected on the corrosion of boiler steel specimens submerged in the steam drums of the experimental boilers used for the tests of boiler compounds. The tests in these boilers were of short duration, never exceeding 350 hours of total exposure, of which not more than 200 hours were during operation at steam pressures of 200, 350 or 600 pounds gauge. As is generally found in corrosion tests, some scatter was inevitable but the general agreement in results was so marked that it is felt the results are worthy of discussion.

In making oxygen determinations every precaution was taken to insure the greatest accuracy. The standard Winkler method for oxygen was used. Great care was exercised in obtaining the samples and in their handling during the making of the tests. It is easily possible, unless precautions are taken, for considerable oxygen absorption to take place during the progress of the test. An absorption of as little as 0.1 milliliter of oxygen during the taking of the sample or during the test introduces an error of about four per cent based on total saturation at room temperature.

ABSORPTION OF OXYGEN BY QUIESCENT WATER.

The general belief that deaerated water in a quiescent state absorbs oxygen at a very rapid rate was found to be somewhat exaggerated. Three-liters of water in a glass beaker, initially nineteen per cent saturated with oxygen at room temperature, were only ninety-three per cent saturated after forty-six hours. One-liter samples in beakers, initially twenty-two per cent saturated, were about eighty per cent saturated after five and one-half hours. It appears, therefore, that water in the quiescent state absorbs oxygen rather slowly and that the process is relatively slower after eighty per cent saturation is reached.

In studying the absorption of oxygen by water not under laboratory conditions, three 8-inch steel standpipes first were used. The pipes were vertical with tops open and exposed to the air. Steam coils were inserted in each so that the contained water could be deaerated by boiling when desired. It was found, however, that the water in the piping after periods as long as ten days showed no more than a bare trace of oxygen in samples taken from near the surface.

It had been expected that much of the oxygen absorbed would react with the exposed iron in the pipe. But it was thought that after a ten-day period this action should have diminished, and that considerable oxygen then would be present, at least in the surface layers. A study of the chemical actions involved led to the conjecture that perhaps the products of the double reaction had an inhibiting effect on oxygen absorption. This double reaction is represented by the two equations:

$$(1): \quad 2\,Fe + 2H_2O + O_2 = 2\,Fe(OH)_2$$

$$(2): \quad 4\,Fe(OH)_2 + 2\,H_2O + O_2 = 4\,Fe(OH)_3$$

This assumption then was tested in the laboratory by adding a small quantity of ferrous hydroxide, obtained by mixing ammonium hydroxide and ferrous sulphate, to a glass beaker containing hot, deaerated water. After four and one-half hours this water was sixty-four per cent saturated, while a sample of distilled water under the same conditions was eighty-five per cent saturated. These tests were repeated several times, using increased amounts of ferrous hydroxide, and it was found in these cases that after forty-eight hours exposure only a slight trace of oxygen could be found in the samples. It was not determined whether the slightly soluble ferrous hydroxide, $Fe(OH)_2$ or the reddish precipitate, $Fe(OH)_3$, or both, are responsible for this action. This explains, however, not only why the water in the standpipes failed to absorb oxygen but also suggests that water in a quiescent state in any iron container will not absorb appreciable amounts of oxygen.

Experiments also were made to determine the oxygen absorption to be expected in an open tank 36 × 30 × 60 inches high. Sampling connections were provided at various levels in the tank; glass windows were installed so as to enable observing the water circulation during the circulation tests. The tank was arranged also, so that horizontal baffles could be inserted fourteen inches from the bottom. The baffles were a neat fit and one had a 3.8-inch diameter hole while the other had two 2-inch diameter holes. The purpose of the baffles was to determine their effect on the absorption of oxygen by the water underneath from that above. The tank was connected by suitable piping to an auxiliary con-

denser unit so that practically deaerated water could be supplied to the tank for either the quiescent or circulating water tests.

In the tests with quiescent water in the large tank, eighteen hours was allowed for each exposure. The first data taken indicated that the iron present was preventing oxygen absorption as found in the standpipe observations. There was a relatively small amount of iron exposed because the metal was galvanized originally. To cover the exposed iron, the inside was painted with two coats of clear shellac. But even this procedure was not effective entirely for the rate of absorption was still very slow.

In order to be certain that this assumption was corerct, one run was made with the water aerated at the start instead of being almost oxygen free. Compressed air was blown into the water and as a result the readings at all levels showed about twelve per cent supersaturation. It was interesting to note in this run that after eighteen hours the water at various levels showed from sixteen to nineteen per cent undersaturation.

Data representative of that obtained in the above type of tests are shown in the following condensed table.

Because of the interesting facts revealed, several tests were made with deaerated water in containers made of different materials. It was found that galvanized iron containers slowed up oxygen absorption considerably. Adding zinc in any form also slowed up the absorption. A 5-gallon oil tin appeared to have a high rate until the surface broke down in various small areas and thereby exposed a small amount of iron, after which the action was slowed perceptibly. Aluminum on the other hand had a marked accelerating effect on the rate of oxygen absorption. Water in an aluminum cup was ninety-nine per cent saturated in 24 hours and after 97 hours showed seventeen per cent supersaturation. These tests were repeated to verify the results reported above.

ABSORPTION OF OXYGEN BY WATER NOT QUIESCENT.

The absorption of oxygen by water in motion was studied in order to determine what occurred in the tanks of the feed water systems as usually installed in Naval vessels. These feed systems are of the open type. The tank, as previously described, was con-

TABLE 1.

OXYGEN ABSORPTION BY WATER IN LARGE TANK — NO CIRCULATION.

Run	Time Hrs.	Time Mins.	Temp.	TOP ml/ liter	TOP % Sat.	BOTTOM ml/ liter	BOTTOM % Sat.	Remarks
(a):	00	00	83	2.8	52	1.8	33	Before shellac was applied.
	16	00	79	2.4	42	2.2	39	
(b):	00	00	74	0.55	9.2	0.47	7 9	After shellac was applied.
	16	00	79	1.8	31	1.0	18	
(c):	00	00	78	0.4	7.0	0.25	4 4	Two hole baffle in place. Bottom
	16	00	84	1 0	19	0.70	13	sample from below baffle.
(d):	00	00	73	1.90	32	0.85	14	Two hole baffle in place. Bottom
	16	15	80	1.95	35	1.40	23	sample from below baffle.
(e):	00	00	87	6.05	112	6 05	112	Two hole baffle in place. Bottom
	18	00	80	4.70	83	4.6	81	sample from below baffle. Water initially supersaturated.
(f):	00	00	102	0.65	14	0.41	9.0	One hole baffle in place. Bottom
	16	30	93	1.55	31	1.25	24.0	sample from below baffle.
(g):	00	00	77.5	0.54	9.4	0.54	9.4	One hole baffle in place. Bottom
	46	00	72	2.15	36	1.85	27.0	sample from below baffle.

nected to a small auxiliary condenser unit so that practically deaerated water could be supplied to the tank, simulating conditions in a standard feed system. The inlet and outlet connections were in the bottom of the tank, with the outlet connection so arranged that an extension to a loofa or filter box compartment in the top of the tank could be added when desired. This provided two methods of circulation, one with a drowned inlet, and one with the waterfall effect resulting from using the filter-box arrangement. The rate of circulation in the tank was about 12,000 pounds per hour, which was equivalent to changing the water in the tank six times during that period. This was comparable to the conditions in a ten-thousand-ton cruiser when operating at 25 knots. Table 2 shows the results obtained under various conditions. There was no top cover on the tank at any time so that the water surface was exposed fully to the air. The readings shown as "in" and "out" are representative also of the water in the bottom of the tank. The condensed data given in Table 2 is representative of the several tests made.

The results shown in Table 2 disclose that the use of a horizontal baffle is of little value in reducing the amount of oxygen absorption from the upper layers of water. This conclusion was put to a more severe test by duplicating runs (a), (b), and (c) of Table 2, and at the same time introducing compressed air at a point eleven inches above the baffle. The inlet and outlet readings for these runs showed that the baffles were only slightly effective in preventing oxygen absorption from the contaminated water above the baffle.

The circulation experiments demonstrated that the loofa or filter-box arrangement, usually found on Naval vessels, is responsible for the major oxygen content found in the feed water. This subsequently has been corrected in new design by placing the filter box in the bottom of the tank. The obvious remedy for existing installations, if its position cannot be changed readily to the bottom of the tank, is to provide a drowned-tube discharge from the filter box.

All the experiments with the simulative feed system indicate that if the condensate return to a properly designed feed tank is well deaerated, and enters the feed tank in such a way that oxygen

TABLE 2.

OXYGEN ABSORPTION IN TANK WITH WATER IN CIRCULATION. INLET AT BOTTOM OF TANK. ABOVE BAFFLE SAMPLES TAKEN ONE INCH ABOVE BAFFLE.

Run	Time		TOP		ABOVE BAFFLE		IN		OUT		Remarks
	Hrs.	Mins.	ml/ liter	% Sat.	ml/ liter	% Sat.	ml/ liter	% Sat.	ml/ liter	% Sat.	
(a):	00	00	0.7	13	0.75	14	0.47	8.7	0.63	11.7	No baffle in place.
	01	00	0.55	11	0.55	11	0.56	10.8	0.54	10.4	Inlet at bottom of tank.
(b):	00	30	0.80	19	0.65	15	0.65	15.0	0.80	19.0	One hole baffle in
	01	15	0.70	16	0.70	16	0.51	12.1	0.52	12.4	place.
	02	00	1.00	22	1.00	22	0.67	15.1	0.97	21.8	Inlet at bottom.
	02	45	1.15	26	0.80	18	0.31	6.8	0.53	11.8	
(c):	00	00	0.6	15	0.55	14	0.30	7.5	0.33	8.2	Two hole baffle in
	00	35	0.4	10	0.40	10	0.43	10.6	0.44	10.9	place.
	01	05	0.5	12	0.30	7	0.24	5.8	0.24	5.8	Inlet at bottom.
(d):	00	00	2.4	43	—	—	0.35	6	1.95	36	No baffle.
	00	45	2.5	42	—	—	0.70	12	2.75	47	Circulation through
	01	30	2.85	48	—	—	0.95	16	3.0	51	loofa box.

absorption is prevented, additional oxygen absorption from the surface of the water is of little moment. The steps taken to prevent surface absorption, such as sealing the tank so as to exclude air, or providing steam blankets, seem to be unnecessary. Even in the extreme conditions of a vessel rolling in a heavy sea-way, it is doubtful whether enough surface oxygen absorption would take place to make any material difference in normal conditions.

CORROSION RESULTS IN EXPERIMENTAL BOILERS.

Figure 1 is a photograph of the experimental boiler used in tests of boiler water treatments. Each unit had only 16.6 square feet of evaporating surface disposed in fourteen one-inch tubes. This small amount of surface was used in order to facilitate rapidity of cleaning and overhaul between tests. The maximum, designed pressure was 600 pounds gauge and this necessitated a relatively large drum in comparison with the small amount of heating surface. This large drum, however, made it possible to expose ten corrosion specimens in each drum. All the specimens used throughout the investigation were cut from the same sheet of boiler steel and were about 3½ inches × 1¾ inches × ⅛ inch in size. Five were mounted in each side of the boiler drum on a rack which was secured to the shell. This rack was so placed that the specimens just were submerged when the water level was at the bottom of the gauge glass. Good electrical contact was provided between the specimens and the rack and between the rack and the boiler shell.

The test pieces were exposed with three different types of finish. Early experiments were with the "as received" metal having mill scale intact. As considerable "scatter" was observed in early runs, the practice of sandblasting some plates was tried. This gave much better results but some difficulty was experienced in cleaning the metal after exposure. Subsequently, both "ground" and "polished" pieces were tried and it was determined that the "ground" type gave the most consistent and reliable results.

The specimens, in all cases, were cleaned carefully, dried, weighed, and mounted shortly before filling the boiler. On completion of a run, they were removed as soon as possible and thoroughly cleaned, dried, and weighed. The loss of weight was

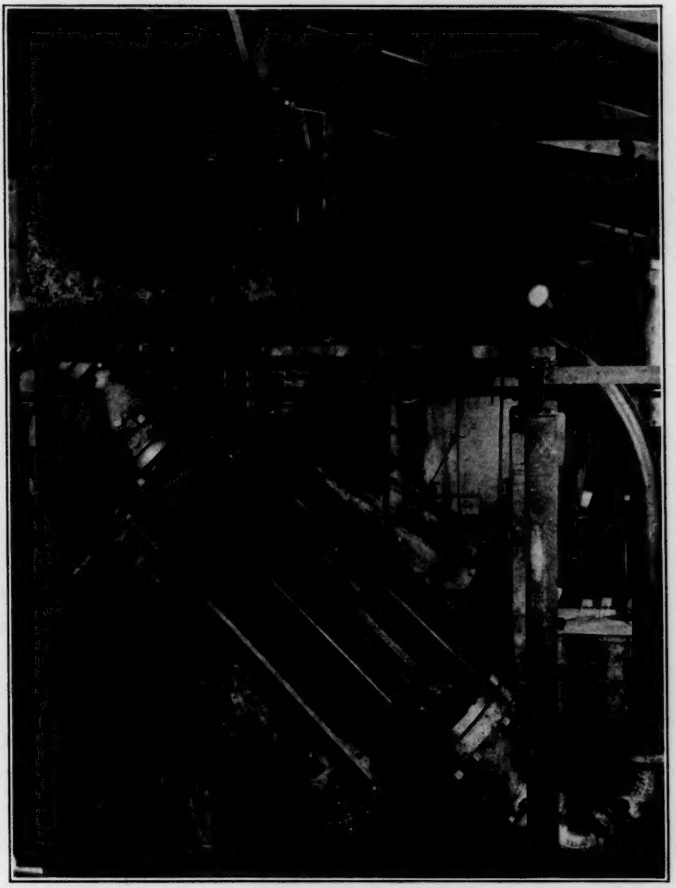

FIGURE 1.

computed as the rate of penetration in inches per year. This gives a more readable form of comparison inasmuch as small variations in specimen size and weight need not be considered when studying the results.

The feed water was saturated with oxygen purposely to obtain the worst possible conditions. The temperature of the feed water was low, because no feed heater was used, and consequently oxygen release in the steam drum was delayed somewhat. In most cases concurrent beaker tests were made using water drawn from the boiler when maximum concentration of all contaminating salts was obtained in the boiler. In the beaker tests, visual observations of the corrosion was noted and when possible data on weight loss also was taken.

The base of the contaminating solution used to determine the value of different boiler water treatments was Severn River Water. This water contains all the salts found in sea water and in the same proportion, but in quantities varying from one-third to one-sixth that of sea water. The boiler water was contaminated quite rapidly until a limit of 70 grains per gallon of chloride was reached, after which the chloride value was kept between 70 and 100 grains per gallon by using the bottom blow. The corrosion specimens were subjected, therefore, to the influence of a diluted sea water. The sodium chloride in sea water is somewhat corrosive, and magnesium chloride is known to be acid forming and highly corrosive under boiler operating conditions. These factors are important in considering the penetration rates obtained.

The results obtained in twenty-four runs with various boiler water treatments grouped themselves into three grades, namely, poor, fair, and satisfactory. In the " poor" class the rates of penetration exceeded 0.012 inch per year, while the middle class was less than .010 and more than 0.008 inch per year. The rates of penetration for the satisfactory class were less than 0.004 inch per year.

Fifteen runs were classed in the satisfactory group and, for every case but one, it appears that maintenance of a satisfactory alkalinity was responsible for the success obtained. During this particular test the alkalinity of the boiler water was generally low and at times the water was slightly acid. In this treatment it

appeared that there was some organic substance present which acted as an inhibitor of corrosion. A study of the various runs indicated that boiler water alkalinity should be in the range between 0.5 and 1.0 per cent of normal. This corresponds to 15 and 30 grains per gallon of sodium carbonate. Higher alkalinities were not investigated as they are not considered desirable for other reasons. The runs in which lower alkalinities predominated gave corrosion results in the fair or poor class.

It was noted in the later tests when ground specimens were used, that Numbers 6 to 10 consistently gave higher corrosion rates than did Numbers 1 to 5. The answer to this divergence was apparent from their relative position in the drum with respect to the internal feed line. Numbers 1 to 5 were remote from the feed line and in the path of the upward circulating steam and water. Numbers 6 to 10 were in the immediate vicinity of the incoming feed and in the path of the water going to the downcomer. The higher oxygen content of the water as it entered the boiler was no doubt the cause of the greater corrosion observed on Numbers 6 to 10. This also demonstrates the destructive effect of the oxygen in boiler water.

Numerous tests of the water in the boiler were made for oxygen. Samples from the lower trycock and from the lowest point of the downcomer failed to show even a trace of oxygen. This would seem to indicate that quite complete deaeration took place in the boiler drum and that any residual oxygen was used up quickly by chemical combination with the iron in the boiler drum and the downcomer.

The rapid release of any oxygen from the feed on entering the boiler is a most desirable condition. It should be remembered that the water fed to these boilers was at low temperatures and was saturated with oxygen, or in other words, contained from 4 to 5 milliliters of oxygen per liter. It appears that by proper design and arrangement of the internal feed line, complete deaeration could be accomplished in the steam drum before any of the water circulates in the boiler proper. It should be possible also to introduce small sheets or protective strips of boiler metal in the wake of the incoming water so that any attack by small residual amounts of oxygen would be concentrated on these strips, which of course could be renewed easily.

It is not contended that the above would cure completely corrosion troubles in a boiler. There are other influences in addition to the oxygen which would still exact their toll of boiler metal. The combination of proper alkalinity and zero oxygen will do much, however, to promote absence of corrosive attack. During the period of a year when the experimental boilers were in operation intermittently under severe test conditions, but with generally well controlled conditions as to alkalinity, no pitting or active corrosion was found in the steam drums or circulating piping.

The information obtained from this experimental work suggests that a further means of minimizing and controlling corrosion lies in making the exposed surfaces more uniform. Sandblasting the interior of a drum to remove all mill scale and other foreign matter should be beneficial. Careful pickling of boiler tubes or passing a burnisher or cutter to remove all mill scale also should be effective. The results of beaker tests show that this procedure will reduce local corrosion and pitting, at least in the idle condition. At the same time it was found that in the tests in which "satisfactory" penetration rates were observed, the sandblasted and "ground" types of specimens showed only general or "all over" corrosive attack, whereas the mill scale specimens invariably had splotchy and irregular corroded areas. It is interesting to note that many boiler drums built today are cleaned by sandblasting.

It is realized that not too great reliance can be placed on the results of short time corrosion tests. At the beginning of the work on boiler water testing it was considered problematical whether any information of value would be obtained from the corrosion specimens. A study of the penetration figures obtained as the testing schedule progressed indicated that a fair consistency of results was being obtained and every effort was made to improve the technique in regard to the corrosion aspect of the test work.

The final study of all the corrosion information obtained, together with the behavior of oxygen in water seems to warrant a consideration of the following general conclusions:

(1). Since the penetration value established for a satisfactory corrosion rate is less than 0.004 inch per year, it follows that a boiler should operate for 25 years and suffer no more than 0.10

inch overall loss of metal thickness on the water side. Inasmuch as most boilers are fed with water having less than 0.25 milliliter of oxygen per liter, while in the test runs of the boilers the feed water was saturated with oxygen, the above limits appear conservative.

(2). As a prime requisite for corrosion control, the boiler water alkalinity must be correctly and continuously maintained within definite limits. The optimum range of total alkalinity appears to be from 12 to 25 grains per gallon expressed as sodium carbonate. These limits also satisfy the other considerations of boiler water treatment which require the maintenance of alkalinity.

(3). The removal of oxygen in the feed water below a value of 0.25 milliliter per liter seems unnecessary in installations where feed line and economizer corrosion is not a problem.

(4). Correct design of the internal feed line should accomplish practically complete feed water deaeration immediately on release of the feed water in the drum. Consideration also might be given to provision of corrosion strips in the wake of the incoming water to absorb any corrosive action from small residuals of oxygen.

(5). The amount of oxygen absorption to be expected while the feed water is passing through a properly designed feed tank is slight.

NOTES ON THE HISTORY OF LUBRICATION.

Part I. General Survey.*

By Mayo D. Hersey, Civil Member.†

While the modern understanding of lubrication rests upon the experiments of Beauchamp Tower and their interpretation by Osborne Reynolds, the work of their predecessors is not without interest. Among the better known investigators in this earlier group are Newton, Amontons, Coulomb, Rennie, Morin, Hirn, Thurston, and Petroff.

EARLIEST INVESTIGATIONS.

To Sir Isaac Newton is attributed the fundamental law of viscous resistance underlying the theory of lubrication, according to which the shearing stress at any point in a fluid is proportional to the rate of shear (Ref. 1)§. To visualize this consider the special case of two parallel surfaces, one stationary while the other is moving tangentially at a constant velocity. Newton's law then states that the resisting force per unit area is proportional to the velocity gradient, or velocity divided by the distance between the two surfaces. The constant of proportionality was later called viscosity. Certain materials, such as oils containing soap, which do not follow this law are described as non-Newtonian liquids.

Amontons (Ref. 2) and later Coulomb (Ref. 4) discovered that the coefficient of friction, or ratio of tangential resistance to the normal component of the load, is constant for dry and imperfectly lubricated surfaces over a considerable range of contact area, speed, and load. They found that the static or starting friction

* To be followed by Part II, Experiments on Journal Bearings; Part III, Physical Properties of Lubricants; and Part IV, Development of the Theory of Lubrication.

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§ References to publications will be found at the end of the article and should be carefully noted by the reader, as the dates and titles are relied upon to convey an interesting part of the story.

was greater than the kinetic friction or friction of motion; and Coulomb gave empirical formulas showing that the static friction increased noticeably with the duration of contact.

Rennie (Ref. 5) extended Coulomb's experiments to include wear and abrasion. He noticed that friction was greatest with soft and least with hard substances; and found that when friction is reduced by the use of lubricants, the amount of reduction depends more on the nature of the lubricant than on that of the solid surfaces.

Morin (Ref. 6) confirmed the Amontons-Coulomb law for a wider variety of materials and conducted systematic experiments on journal bearings. By analogy with the preceding work on flat surfaces, Morin expressed his results in terms of the ratio of the frictional resistance at the rubbing surfaces to the total load on the bearing, a ratio now commonly known as the coefficient of friction of the bearing. He found the coefficient was reduced to about one-half when the lubricant was continuously renewed. He noted that the difference between the static and kinetic coefficients was most pronounced for compressible substances, and pointed out the effect of vibrations in reducing static friction.

Hirn (Ref. 8) discovered the effect of running-in, calling attention to the fact that lubricated bearings must be run continuously for a certain time before the friction settles down to its final steady value, and that this value is lower than the initial value. When the temperature is not artificially regulated, he concluded that the friction of lubricated surfaces might be taken as roughly proportional to the square roots of the area, load, and speed. He gave an empirical formula for the variation in friction with rise of temperature which is in close agreement with our present knowledge of the effect of temperature on viscosity. Hirn was the first to prove experimentally that heat disappears when work is done by a steam engine; and it is interesting to note that his measurements were so carefully conducted as to lead to a reasonably accurate value for the mechanical equivalent of heat.

Thurston was a pioneer in the effort to place the comparative testing of lubricants on a systematic basis, and succeeded in drawing attention to the great practical importance of reducing friction losses in machinery (Refs. 13, 14, 23). He appears to have been

the first to discover the existence of a minimum point when the coefficient of friction is plotted against speed or temperature. To Thurston is due the widely quoted rule that the safe load per unit area is inversely proportional to the speed. This he derived from observations of the bearings that were in use on naval steamers over seventy years ago. Although Thurston's rule is not applicable to modern high speed bearings, it illustrates perfectly the need for some definite relation connecting load capacity with speed as a starting point for bearing design.

Petroff was awarded the Lomonossoff prize of the Imperial Russian Academy of Sciences for his first investigation, published in 1883 (Ref. 17). At a time when only animal and vegetable oils were commonly recognized as lubricants, Petroff demonstrated the value of the Russian petroleum oils by showing that their utility depended merely on selecting a suitable viscosity for each application. He also deduced the first mathematical formula for the friction of a journal bearing, treating the case of a full bearing operating with a uniform film thickness. This condition is approximately realized in practice when the bearing is lightly enough loaded, or running at a high enough speed. Petroff's formula was derived from Margules' equation for the concentric cylinder rotation viscometer (Ref. 16). The terms originally included for the so-called external friction of the lubricant were afterwards found negligible. Petroff's studies were continued and compared with experimental results in a further series of papers (Refs. 20, 26, 29, 36, 43). These comparisons indicated that the effective film thickness was inversely proportional to the square root of the load, in agreement with Hirn's observations.

Other investigations of some importance prior to the time of Tower and Reynolds are those of De la Hire (Ref. 3), Brix (Ref. 7), Bochet (Ref. 9), Jenkin and Ewing (Ref. 10), Kimball (Refs. 11, 12), and Woodbury (Ref. 15).

TOWER AND REYNOLDS.

Tower's experiments were conducted for a Committee of the Institution of Mechanical Engineers. This Committee published two reports on the friction of journal bearings (Refs. 18, 24)

followed by two on the friction of collar and pivot bearings (Refs. 30, 34); the whole series extending from 1883 to 1891.

The journal bearings were partial bearings of about 155 degrees arc, made of gun-metal brass. The journal was 4 inches in diameter; the bearings 6 inches long. Oil was supplied first by a syphon lubricator, then by a pad, and finally by means of a bath. The lubricants included two animal oils, lard and sperm; two vegetable oils, rape and olive; also a mineral oil and a mineral grease. Operating conditions were varied over the range from 100 to 450 R.P.M. and from 100 to 625 pounds per square inch in most of the tests.

The friction with bath lubrication was found surprisingly low. The comparative friction with the six lubricants gave values consistent with our present knowledge of their probable viscosities, although Tower had not determined the viscosity of any of them. The coefficient of friction increased less rapidly than the first power of the speed, and decreased with rising temperature. The coefficient varied approximately in the inverse ratio of the load; which is another way of saying that the frictional resistance itself was nearly independent of the load.

All the information which the Committee sought for concerning friction relations was obtained. But now observe carefully what happened. In anticipation of installing a lubricator, a half-inch hole had been drilled in the center of the brass. An outflow of oil then occurred when running the machine. To prevent it, a wooden plug was driven into the hole; but on starting up again, the plug was slowly forced out. This precise moment appears to have been the turning point in the history of lubrication.

A pressure gauge was attached and indicated a true fluid pressure in the film, at the center of the bearing, sometimes as great as twice the mean pressure computed by dividing the total load by the projected area of the bearing. Accordingly, the Committee thought it worth while to construct a second bearing as nearly as possible a duplicate of the first except that nine small holes for pressure measurement were located in the first 3 inches of the length of the bearing. Assuming perfect symmetry, this would be equivalent to pressure observations at 15 different points. In this way the journal bearing experiments were concluded by a

determination of the longitudinal and circumferential pressure distributions for typical operating conditions.

The great lesson to be learned from these experiments, according to Tower, was the importance of a liberal supply of the lubricant. In this manner the brass was caused to float on a liquid film, with a corresponding reduction in power loss, and almost complete elimination of metallic wear. Tower's remarks on this point, quoting from the published discussion (Ref. 18 (b), page 30) are in part as follows:

> "No doubt a practical recognition of the value of profuse lubrication was seen in the trial trips of large marine engines, especially when there was a premium for extra horsepower; but in those cases the oil generally ran straight from the bearings into the bilge, and was wasted. The present experiments showed that the rate of lubrication adopted in such trial trips should be kept up at all times, though the wastefulness need not accompany it."

The conclusions to be drawn from these experiments concerning the best location for the oil inlet are also of importance. Quoting again from Tower's remarks (Loc. cit., page 35),

> "The journal ought to be oiled at some part where there was no pressure, trusting to the adhesion of the oil to the journal for carrying it to the place where there was pressure. If the oil was applied in the middle of the seat of pressure, it would be squeezed out and escape just where it was most wanted to counteract the pressure."

Reynolds perceived at once, from Tower's experiments, that lubrication was a hydrodynamic action depending on the viscosity of the lubricant (Ref. 27). Petroff had recognized the connection between viscosity and friction, and published a mathematical solution for concentric bearings. But it remained for Reynolds to explain the load carrying power of the oil film, and to extend the friction problem to the more difficult case of an eccentric bearing. His classical paper of 1886 may be considered as containing three principal contributions, (1) a general picture of the physics of

lubrication, potentially capable of a more complete mathematical formulation than has yet been undertaken; (2) a differential equation for the pressure distribution in the film, capable of many future applications not yet worked out; and (3) application of the foregoing to the particular circumstances of Tower's experiments.

The application to Tower's experiments was made unnecessarily difficult by the fact that Tower had not attempted to measure the clearance, the film temperatures, or the viscosities of the oils. Reynolds' ingenuity served to deduce approximate values for the clearance (difference in radii) and for the film temperatures with the aid of a careful experimental determination of the viscosity of olive oil as a function of temperature. The result of his analysis, notwithstanding the uncertain factors mentioned, was to confirm the essential truth of the hydrodynamic theory.

That a Committee of the Institution of Mechanical Engineers should have overlooked factors that appear to us now so obvious as clearance and viscosity is accounted for by the fact that whereas we have the hydrodynamic theory to tell us what to look for, they did not.

The theory undertakes to show what relations subsist between the various performance characteristics, considered as dependent variables; and the operating conditions and design factors, considered as independent variables. Among the performance characteristics are the coefficient of friction, pressure distribution, eccentricity, and angular position of the line of centers. Among the operating conditions and design factors are the load, speed, viscosity of lubricant, absolute size of the bearing, and its geometrical shape in every particular. These relationships are to be examined in detail later. It need only be stated at this point that the most significant result of Reynold's theory is the principle of the oil wedge, or converging film. The lubricant adheres to both the moving surface and the stationary surface; and by virtue of its viscosity, it develops a positive fluid pressure in the converging portions of the film. This pressure supports the load and prevents metallic contact. No such pressure can be developed between strictly parallel surfaces.

That the principle of the converging film had also been recognized by the late Lord Rayleigh will appear from the following remarks, quoted from his Presidential Address at the Montreal meeting of the British Association (Ref. 21):

> "I must not forget to mention an important series of experiments upon the friction of oiled surfaces, recently executed by Mr. Tower for the Institution of Mechanical Engineers. The results go far towards upsetting some ideas hitherto widely admitted. When the lubrication is adequate the friction is found to be nearly independent of the load, and much smaller than is usually supposed, giving a coefficient as low as 1/1000. When the layer of oil is well formed, the pressure between the solid surfaces is really borne by the fluid * * *. In order to maintain its position, the fluid must possess a certain degree of viscosity, proportionate to the pressure; and even when this condition is satisfied it would appear to be necessary that the layer should be thicker on the ingoing than on the outgoing side."

Reynolds believed the hydrodynamic theory applicable in its qualitative aspect to a very wide variety of practical conditions. This becomes evident from the last section of his paper, where he states that

> " * * * the result of the whole research is to point to a conclusion (important in Natural Philosophy) that not only in cases of intentional lubrication, but wherever hard surfaces under pressure slide over each other without abrasion, they are separated by a film of some foreign matter whether perceivable or not. And that the question as to whether this action can be continuous or not turns on whether the action tends to preserve the matter between the surfaces at the points of pressure as in the apparently unique case of the revolving journal, or tends to sweep it to one side as is the result of all backwards and forward rubbing with continuous pressure."

While Reynolds' paper of 1886 is notable for its involved mathematical character, it is not so commonly known that he was also

the author of a shorter and more readable article (Ref. 44) in the Encyclopedia Brittannica. This will be found in the tenth to the thirteenth editions, inclusive.

CLOSING YEARS OF THE NINETEENTH CENTURY.

Contemporary with or closely following the work of Tower and Reynolds may be cited the journal bearing experiments of Deprez, Wellington, Goodman, and Denton; the first gear experiments by the late Wilfred Lewis; and investigations of possible slip at the interface between liquid and solid, by Couette and by Wetham.

Deprez (Ref. 19) appears to have been the first to utilize the well known deceleration method for journal friction measurement. This method was further applied by Dettmar (Ref. 41).

Wellington (Ref. 22) was able to confirm, by laboratory tests, the comparative friction of two types of bearings already tested as railway equipment.

Goodman (Ref. 28) supplemented Tower's experiments by observations on the effect of varying the length of the arc of contact of partial bearings; and by demonstrating the building up of an oil film by actual micrometer measurements.

Denton (Ref. 33) tested heavily loaded bearings. He proved that overheated bearings might be cooled off, at the cost of more rapid wear, by throwing into the lubricant a liberal quantity of sand or emery.

Lewis made a comparison of spur gear and worm gear friction losses (Ref. 25), from which it was clearly evident that spur gears, as a type, have the higher efficiency.

Couette (Ref. 31) extended Reynolds' study of critical velocities to the problem of rotating concentric cylinders. The constant determined by Couette's experiments stood for a long time as the most probable value applicable to journal bearings. From Couette's data it would appear very unlikely for turbulent motion to occur in the lubricating film.

Neither Couette nor Wetham (Ref. 32) observed the slightest evidence of the alleged slip between liquids and solids. This confirmed the assumption of Reynolds that perfect adhesion may be depended on in the ordinary problems of viscous resistance.

Albert Kingsbury, when working in the laboratory of Professor Thurston at Cornell, 1888-1889, found that certain differences in friction, commonly attributed to the composition of the bearing metals, disappeared when sufficient care was taken in accurately fitting the bushings to the journal (Ref. 70). This is in accord with the theory of Reynolds, and further demonstrates the prime importance of accurate mechanical workmanship in lubrication investigations.

Kingsbury discovered about 1895, by microscope observations on mild steel in a cutting-off operation, that the lubricant is drawn into the space between the bottom of the chip and the top surface of the tool as a result of the partial vacuum formed in the crack which precedes the point of the tool. This observation, although not published until a later date (Ref. 49), throws considerable light on the seemingly paradoxical action of cutting fluids.

A machine for testing the friction of screws was described by Kingsbury at the 1895 Annual Meeting of the American Society of Mechanical Engineers (Ref. 35). Mineral oil, lard oil, and mineral oil containing graphite were compared on both ferrous and non-ferrous metals under loads up to 14,000 pounds per square inch. These were possibly the first experiments, under scientifically controlled conditions, on the characteristic now known as oiliness.

Kapff, in 1898, concluded from his experiments (Ref. 40) that some other property besides viscosity is influential in determining friction. This characteristic was called *oiliness* by Archbutt and Deeley in 1900 (Ref. 42).

Returning to the study of perfect, or fluid-film lubrication, Kingsbury conducted his classical experiments on the air-lubricated journal bearing. A report of these experiments was published in 1897 by the American Society of Naval Engineers (Ref. 37). Careful measurements were made, at varying speeds, of the pressure distribution in the film and the position of the journal in the bearing as well as of the friction torque acting upon the journal. Confirmatory results were obtained using hydrogen as the lubricating fluid. These observations were in as close agreement with Reynolds' theory as could be wished, considering that the lubri-

cant used was not incompressible. It was evident that the essential property of a lubricant is something possessed in common by liquids and gases, namely, viscosity; and that the essential mechanical requirement for perfect lubrication is the converging film.

Film thickness measurements based on the electrical resistance of the oil film were described by Wadsworth in 1897 (Refs. 38, 39).

Kingsbury now applied the principle of the converging film to the design of thrust bearings. This was done by dividing the bearing surface into segments, each one pivoted so that it was free to adjust itself automatically to the proper angle of inclination with the opposite rubbing surface, or runner. The first Kingsbury thrust bearings were constructed at the New Hampshire State College. They were tested in comparison with ordinary thrust bearings on the machine already mentioned, which had been used for determining the friction of screws. These tests were reported in theses by H. C. Baker and H. N. Putney in 1899 (Ref. 70). Further tests were conducted at the Worcester Polytechnic Institute during the following year, 1899-1900; and the Kingsbury machine on which all these tests were made may still be seen by visitors at the Institute, together with the original air-lubricated journal bearing.

BEGINNING OF THE PRESENT CENTURY.

Thus by the close of the nineteenth century the fundamental principles of lubrication were understood and were being usefully applied. A pivoted segment bearing similar to the Kingsbury type was independently developed in Australia by A. G. M. Michell as a result of studies conducted during 1902-1904 (Refs. 53, 71). Both inventors attributed their inspiration to the theory of Osborne Reynolds. Subsequent tests by Howarth and others (Refs. 52, 58, 59) have fully demonstrated the superiority of the pivoted segment thrust bearing over the other types previously used, particularly as applied to the larger hydroelectric and marine installations. The Elliott Cresson medal of the Franklin Institute was awarded to Albert Kingsbury in 1923 for his development of the Kingsbury thrust bearing. Other medals were awarded later.

The first third of the twentieth century has been characterized by: (1) Qualitative and partly quantitative experiments on the lubrication of the more difficult machine elements, such as gears, engine cylinders, cutting tools, and screw threads. (2) Repeated efforts to gain a better understanding of the phenomena of imperfect lubrication. (3) Quantitative experiments on journal bearings. (4) Investigations of the properties of lubricants. (5) Further development of the theory of lubrication, with applications to bearing design.

Of these five subjects, the first two will be dealt with briefly below, while the last three are reserved for future discussion.

LUBRICATION OF DIFFICULT MACHINE ELEMENTS.

Gears. The pioneer work of Lewis has been mentioned (Ref. 25). A proposed new testing machine was described by him in 1923 (Ref. 60) and afterwards installed at the Massachusetts Institute of Technology, where investigations have been conducted by Earle Buckingham (Refs. 64, 68, 73).

The regenerative method of gear testing invented by Albert Kingsbury (Ref. 48) is incorporated in the Lewis machine. Previous methods called for separate measurements of input and output, the power loss to be computed by subtraction. A little arithmetic reveals the tendency of that procedure toward serious magnification of errors when the efficiency is as high as 95 to 98 per cent. Kingsbury's method provides means for applying the full tooth loads to the gears while supplying and measuring only the amount of power consumed by friction.

An independent application of the regenerative principle to worm gear testing by Lanchester has been described in reports from the National Physical Laboratory (Refs. 46, 55). These investigations evidenced the superiority of fatty over mineral oils for worm gear lubrication.

A study of the efficiency of gear drives was conducted by Allen and Roys at the Worcester Polytechnic Institute (Ref. 50). The efficiency and durability of spur gears were investigated by Ham and Huckert at the University of Illinois (Ref. 62).

Experiments by S. A. McKee and T. R. McKee, for the American Electric Railway Engineering Association (Ref. 76) showed

how the efficiency of spur gear and worm gear drives varied with the speed, load, temperature, and type of lubricant used.

Hyde, Tomlinson and Allen (Ref. 82) found that a very high degree of efficiency and freedom from wear may be reached in gears that are properly designed and lubricated.

Automotive engineers have been designing rear axles for progressively increasing tooth pressures and demanding extreme pressure lubricants which will operate without seizure under severe conditions. This requirement has stimulated the production of lubricants containing chemically active ingredients (Refs. 77, 84).

Piston and cylinder friction. Among the best known experiments on cylinder friction are those of Flowers (Ref. 47), Stanton (Ref. 61), and Thornycroft and Barton (Ref. 72). From the data given by Flowers on steam cylinder lubrication at two temperatures it would appear that the friction was considerably affected by change in viscosity. Stanton believed cylinder friction is of the boundary or imperfect lubrication type, independent of viscosity. Thornycroft and Barton, on the contrary, concluded that the friction of internal combustion engines is chiefly of the viscous type.

Cutting tool lubrication. While Kingsbury's observations (Ref. 49) provided an answer to the question how the lubricant is able to penetrate to the point of the tool, there are many other curious and important questions still unsettled. Some of these were reviewed in Progress Report No. 1 of the A. S. M. E. Sub-Committee on Cutting Fluids (Ref. 69). That report also contains a bibliography of the subject up to 1928. Recent investigations in Germany are summarized in the treatise by Gottwein (Ref. 66).

Friction of screws. No experimental work of a fundamental nature on the friction of screw threads has come to our attention between the time of Kingsbury's investigation in 1895 and that of Ham and Ryan, at the University of Illinois, in 1932 (Ref. 81).

PERFECT AND IMPERFECT LUBRICATION.

A useful distinction can be made between thick film, or perfect lubrication, and thin film, or imperfect lubrication. The dividing line between these two states depends on the roughness of the

surfaces in any particular case. In general it may be assumed that imperfect lubrication involves the coexistence of fluid film lubrication with boundary lubrication.

Boundary lubrication has been described by Sir William Hardy (Ref. 57) as a condition in which the metal surfaces are protected, and altered in their properties, by an adsorbed layer of the lubricant on each surface, without any free liquid between. It is a condition closely approaching solid friction, but in which the coefficient of friction depends jointly on the nature of the solids, and on that of the lubricant applied.

Langmuir (Ref. 56) believed the adsorbed layer of lubricant on each metal surface to be only one molecule thick. Kingsbury's experiments with a rotating tapered plug (Ref. 51) showed no departure from the laws of thick film lubrication down to films at least as thin as one forty-thousandth of an inch. Bulkley's experiments with extremely fine capillary tubes (Ref. 74) showed that if the adsorbed layer of lubricant was of a plastic or non-fluid consistency it must be at least as thin as one millionth of an inch.

Imperfect lubrication may result from an inadequate supply of the lubricant; from excessive load, especially if localized due to rough spots, shaft deflection, or temperature inequalities; or from the viscosity and speed being too low to build up the requisite film pressure. It is frequently experienced with parallel bearing surfaces, as in ordinary collar and pivot bearings. The principal phenomena of imperfect lubrication may be classed under three heads—wear, seizure, and oiliness.

The status of wear investigations has been summarized by Jordan (Ref. 75). The study of physical and lubrication factors has clearly not kept pace with the efforts already devoted to the metallurgical factors. The Amsler and Timken machines (Refs. 65, 80) are among the best known types of wear testing equipment in which both the metal and lubricant may be varied.

Seizure and the so-called film strength, or film breakdown, phenomena have chiefly been investigated in connection with journal bearings. The consideration of seizure will be reserved for Part II except to note the recent development of a machine for com-

paring the load capacities of lubricants by S. A. McKee, F. G. Bitner and T. R. McKee (Ref. 88). This investigation was part of a study of extreme pressure lubricants for rear-axle gears, and brought out strikingly the effect of the rate of loading as an essential variable.

The problem of oiliness was set forth by Kingsbury some thirty years ago in his paper describing a new oil testing machine (Ref. 45). Among the kinetic oiliness machines developed since that date are those of Deeley (Ref. 54), Woog (Ref. 63), Herschel (Ref. 67), Voitländer (Ref. 79), Wells (Ref. 78) and Neeley (Ref. 83). In addition, there have been many investigations by Hardy and others utilizing simple forms of static friction apparatus; also numerous proposals for indirect measurement, based on such phenomena as the heat of wetting, rectification of alternating currents, etc. Oiliness has been defined as that which may cause a difference in friction between two tests, under identical conditions, in which the lubricants have the same viscosity at the test temperature and atmospheric pressure. The definition of oiliness, hypotheses for explaining oiliness, and some of the requirements for a satisfactory test are discussed in a recent paper (Ref. 87). Further consideration of oiliness is reserved for Part III.

Imperfect lubrication phenomena are closely related to the spreading and wetting tendencies of the lubricant, and to the roughness characteristics of the bearing surfaces. Spreading of lubricants on metal surfaces has been investigated by Woog (Ref. 63) and more recently by Bulkley and Snyder (Ref. 86); and roughness measurement by Abbott and Firestone (Ref. 85).

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THE PRINCIPLES AND PRACTICE OF BOILER WATER TREATMENT AS APPLIED TO THE NEEDS OF THE NAVY.

By Robert C. Adams, Jr., Associate Member,*
and
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The advantages of proper treatment of boiler-water as an aid in the preservation and efficiency of operation of steam boilers have been appreciated insufficiently because they have not been thoroughly understood. Corrosion can be reduced to an inconsiderable amount and priming and foaming can be avoided. The formation of boiler-scale can be prevented and existent scale can be removed. In this article the theories of the cause and prevention of scale-deposition, carry-over and corrosion will be discussed. In each case the exposition of the theory will be followed by a presentation of the application of the theory to the needs of the Naval Service.

THEORY OF FORMATION AND PREVENTION OF BOILER-SCALE.

The effect of temperature on the solubility of a substance determines whether or not the material will form a scale. Salts whose solubility increases with increase in the temperature of the solution, that is, salts which have positive solubility, do not form scale; scale is formed by those salts whose solubility decreases with increase in the temperature of the solution, which are the salts with negative solubility. In general the scale-forming salts also are relatively insoluble, but it is not their low solubility but their negative solubility, which is the real criterion of their scale-forming properties.

All successful modern methods for the treatment of boiler feed-water are based, either admittedly or involuntarily, upon adherence to this principle. The principle itself was established as the result

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of an extended investigation by the Bureau of Mines under the direction of Dr. R. E. Hall. Like many other scientific principles, once discovered, it appears so simple that the wonder is that it had not been recognized earlier.

All waters contain impurities in greater or less amount. Among these impurities there generally will be found some scale-forming salts. Because of their low solubility, and not because of their negative solubility, the scale-forming salts approach the saturation value corresponding to the boiler-water temperature after very few concentrations of water in the boiler. The effect of the negative solubility then becomes apparent. The boiler-water enters the lower end of the tubes carrying an amount of scale-forming salts which approaches or equals saturation, at the temperature corresponding to the working steam pressure. The combination of heating and evaporation within the tubes decreases both the capacity of the water to hold these salts in solution and the amount of water available to dissolve the salts. The result is the separation of the excess of scale-forming solids. The separation occurs where the greatest super-saturation exists, which is in the layer of superheated water in contact with the tube-surface. In this way the scale is deposited directly upon the tube metal.

There are two factors which effect scale deposition: supersaturation by increase in solution temperature and concentration by evaporation. Hall chiefly considered the first and by his exposition of it, laid the basis for intelligent, calculated treatment of boiler-water. Later work by Dr. E. P. Partridge at the University of Michigan has demonstrated that the second factor also has great importance, particularly in boilers which operate at such high rates of evaporation as are becoming frequent in modern practice.

Partridge has expounded a bubble theory of scale-formation. In the evaporation of water, bubbles of steam are formed on the tube surfaces. Each bubble starts as a minute pocket of steam on the evaporative surface, and grows, by the evaporation of water from its edges and inner surface, until its buoyant effect is sufficient to tear it from the surface so that it can float to the top and there discharge its steam. Each steam bubble represents a minute particle of water from which all dissolved solids have

been removed. The process of removal determines whether the concentration of the boiler-water increases harmlessly or whether scale is deposited on the tube surfaces.

The area of tube surface beneath a growing steam bubble is practically insulated, since the thermal conductivity of a gas is very slight. The heat which is conducted to this area through the tube wall cannot be transferred continuously to the boiler-water. A small part of this heat is conducted through the steam and causes some evaporation from the hemispherical water surface which surrounds the expanding steam bubble.

The salts contained by the water before evaporation are forced into the boundary surface of the bubble. The major portion of the heat coming through the tube wall beneath the bubble is conducted to the circumference of the bubble where the steam, the water and the hot metal meet. In the vicinity of this roughly circular line the rate of heat transfer per unit of area is much greater than the average for the whole tube and many times as great as that corresponding to the commonly-used rate of evaporation for the boiler as a whole. In this circumference the effects of both factors for scale formation: concentration by evaporation and super-saturation by heating, are intensified, so that when the bubble pulls away from the tube surface a line of crystals is left to mark the ring. More bubbles form and leave behind rings of crystals which become interlaced and built upon until the original ring structure becomes almost indiscernible. With a motion-picture camera, Partridge has photographed the formation and growth of scale in such a manner as to demonstrate the foregoing explanation. Some of his pictures are reproduced in Figures I and II.*

So far the mechanism of scale-formation has been outlined without any suggestion as to the possible preventive measures. The methods of scale prevention were developed by Hall as soon as the effect of negative solubility was understood.

Boiler-scale can be prevented by converting the molecules of scale-forming, negatively-soluble salts into molecules of non-scale-forming, positively-soluble salts. It also has been proposed to achieve protection simply by attaching the scale-forming molecules

* Figures I and II are reproduced from Engineering Research Bulletin 15 of the University of Michigan by permission of the author, Dr. Everett P. Partridge, and of the Department of Engineering Research.

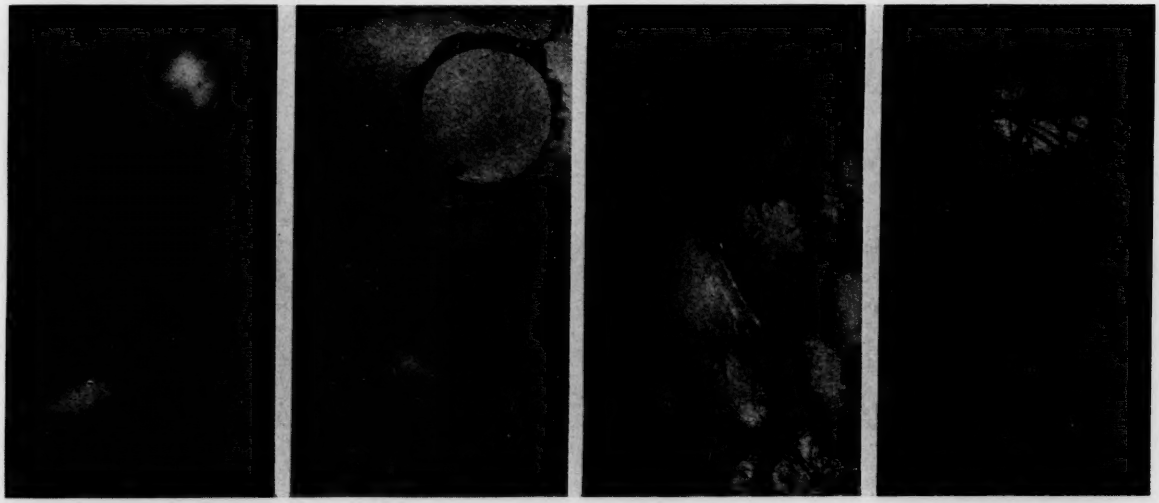


FIGURE I.—DEPOSITION OF CRYSTALS OF CALCIUM SULFATE BY BUBBLE EVOLUTION AT EVAPORATIVE SURFACE (x75.).

A—Bubble attached to surface.
B—Ring of crystals left by bubble—2 minutes later than A.
C—Other rings left by bubbles—6 minutes later than A.
D—Growth of crystals—30 minutes later than A.

FIGURE II.—DEPOSITION OF CRYSTALS BY BUBBLE EVOLUTION.

Several stages in the process of scale formation are shown. At the left may be seen the shadows of three bubbles attached to the surface. The rings of minute crystals left by two of these bubbles may be seen in the next frame. The deposition of new rings and the growth of previously deposited crystals are shown in the other exposures.

to non-scale-forming molecules. Methods of control which will assure such a successful attachment are not yet available. Prevention by conversion is the only method explained in this paper.

Molecules of salts in solution dissociate into ions. For example common salt, sodium chloride, when dissolved in water dissociates into sodium and chloride ions:

(1) $NaCl + H_2O \rightleftharpoons Na^+ + Cl^- + H_2O$

Since the water does not react with the salt it may be omitted from the equation, which would then appear as follows:

(2) $NaCl \rightleftharpoons Na^+ + Cl^-$

Upon evaporation the ions recombine and the salt, NaCl, is recovered.

All salts exhibit this phenomenon of dissociation to a greater or less degree. A salt, AB, in solution would dissociate into A^+ and B^- ions, and in the same solution a salt, XY, would yield X^+ and Y^- ions on dissociation. The solution would in this way contain four ions, A^+, X^+, B^- and Y^-. If the solution were evaporated it is improbable that all ions could find their original partners. The residue on evaporation would be a mixture of AB, AY, XB and XY.

If the solubilities of all four salts are about the same, a more or less random mixture of the four will be obtained. However, if one salt, for example, AY, is much less solubile than the others, it will predominate in the residue. After evaporation of the mixed solution is begun, the saturation point of the least soluble AY will be reached before that of the other salts. If XB is very soluble, while AY is quite insoluble, a mixture of AB and XY may be converted almost completely into AY and XB. The AY will precipitate, while the XB will remain in solution.

Scale can be prevented by the application of this method of conversion. If AB, because of its negative solubility, is a scale-forming salt, the treating chemical XY should be chosen to obtain desirable properties in the product AY. AY should not only be less soluble than AB but also should have a positive solubility. Otherwise the amount of scale will be reduced somewhat, but scale will not be prevented. Laboratory experiments can determine the ratio of the concentrations of Y^- and B^- necessary to insure

the complete conversion of AB to AY before the saturation point of AB is reached. Control consists in maintaining the concentration of Y^- safely above the determined, dangerous minimum.

Even with these precautions a ring of crystals still will be formed each time a bubble of steam leaves the tube wall. The boiler-water must be sufficiently dilute, the deposited crystals must be sufficiently soluble, and there must be present a sufficient excess of protecting chemical, so that each time a bubble leaves a ring, the water coming in to fill the space the bubble left can dissolve the tiny ring of crystals almost instantaneously.

Thus it can been seen that with increasing rates of evaporation the need is becoming more acute for increased knowledge and vigilance in the care of boiler-water.

PREVENTION AND REMOVAL OF SCALE IN THE NAVY.

In the Naval Service, where all fresh water is obtained by distillation, the necessity for treatment of boiler-water may not be readily apparent. Any engineer officer knows that there are a multitude of opportunities for contamination of the distilled water. The methods of treatment applicable to the Naval Service will be discussed in the light of the principles of scale-formation and scale-prevention, which have been presented.

The elimination of feed-water contamination at its source usually is a mechanical instead of a chemical problem. The need and method of replacement of a leaky condenser tube, or the diversion from the hot well of salty drains generally are known. The means for the protection of the boiler against the effects of contaminated feed-water until time is available for complete mechanical correction are not so well known.

Sea water is the most common contaminant of feed-water. It gains access to the fresh water as carry-over from the evaporators, as leakage through the distiller coils, as seepage into reserve-feed bottoms, or as condenser leakage. Of these, condenser leakage is the most important and the largest source of sea water contamination. The Regulations provide for sufficiently frequent tests of all condensate and distillate to detect the entry of sea water in large amounts, but there usually is a continuous slow leakage which cannot be stopped entirely.

After condenser and distiller leakage have been cared for, the contamination which occurs in the feed bottoms must be considered. Distilled water attacks iron and, to a lesser extent, attacks the coatings which may be applied for the protection of the iron. A thin wash of Portland cement often is used for coating feed bottoms. While cement wash is a fairly satisfactory barrier to corrosion, it is a fruitful source of possible boiler-scale.

Portland cement is a complex calcium silicate which contains iron, aluminum and magnesium in various proportions. Distilled water stored for several weeks in a tank coated with cement wash will dissolve, and tend to become saturated with, the various constituents of the coating. In general, the salts of the heavy metals which compose Portland cement are those which form boiler-scale.

The first step in preventing boiler-scale is the determination of the extent of the contamination. This means analysis of the feed-water. A multitude of various ions are present in sea water, and the total concentration of the salts varies markedly from southern to northern latitude and from ocean to ocean. The ratios of the concentrations of the various ions with each other and with the total concentration, are remarkably constant. Since these ratios are known, if a determination of potassium ion, K^+ were made on a sample of sea water, an accurate estimate could be made of the concentration of Na^+, Mg^{++}, Cl^-, SO_4^{--}, and of the other ions present. Because this relationship exists, it is logical to determine the most abundant ion, which is chloride, Cl^-, particularly since the determination of chloride is both accurate and rapid.

The determination of chloride is made by the use of silver nitrate. A solution of silver nitrate of known strength is added to a measured amount of water. Since silver chloride is virtually insoluble in a neutral solution, the chloride is precipitated as silver chloride. The reaction is similiar to the hypothetical reaction between AB and XY outlined in the discussion of scale prevention.

(3) $Cl^- + Ag\ NO_3 \rightarrow AgCl + NO_3^-$

A small amount of a soluble chromate salt is added as an indicator. Silver chromate also is insoluble, but it is not quite so insoluble as is silver chloride. As long as there are chloride ions in solution the silver ions are removed so fast that insufficient silver ion is present to

saturate the solution with silver chromate. When all the chloride has been precipitated, a very slight excess of silver ion will saturate the solution with silver chromate which then separates as a bright orange precipitate.

(4) $2\,AgNO_3 + Na_2CrO_4 \rightarrow Ag_2CrO_4 + 2NaNO_3$

The first trace of orange color, which persists after the addition of silver nitrate has ceased, indicates that all the chloride has been precipitated.

It is possible to figure, from the chloride concentration, the concentrations of the other ions in a water but such a calculation seldom is made. Because the relationship is constant the calculation becomes unnecessary. The chloride determination is useful also as a measure of total concentration in boiler-waters since the common chloride salts are soluble far beyond the range of concentrations usually found in boiler-waters.

If sea water were the only contamination in boiler feed-water, the chloride test would be sufficient to determine the amount and kind of scale-forming salts present in the water. The avidity of distilled water is such that it dissolves something from each surface it touches in its progress from the evaporators to the boilers. Fortunately there is available a simple method for the direct determination of scale-forming salts. This method is the analysis of the water for "hardness."

The method of determining "hardness," or scale-forming salts, is to measure the amount of a standardized solution of soap required to form a lather on a sample of known size. The ordinary soap in common use is known chemically as "sodium soap." This is because it is made by the reaction between sodium hydroxide, lye, and a fatty acid. If stearic acid is taken as a representative fatty acid, and glyceryl stearate as a representative fat, a somewhat simplified equation may be written for the manufacture of soap.

(5) Sodium hydroxide + glyceryl stearate → sodium stearate + glyceryl hydroxide (glycerin)

Sodium stearate is a soluble soap. Similar soluble soaps may be made by the same process by using another strong alkali such as caustic potash (potassium hydroxide) or liquid ammonia (ammonium hydroxide), instead of lye. Furthermore, calcium soaps, lead soaps, magnesium soaps, and others may be made by the same

generic reaction of an hydroxide with a fatty acid. However, these latter soaps do not dissolve in water to form a lather and so are classed as "insoluble" soaps.

The salts which occur commonly in boiler feed-water and whose metals form insoluble soaps, in general are the salts which form scale. Herein is the value of the soap test to the boiler operator. Soluble, sodium soap in the presence of salts of the heavy metals is converted to insoluble soap.

(6) Sodium soap + calcium sulphate → sodium sulphate + calcium soap.

Until all of the scale-forming salt has been precipitated as insoluble soap there can not be sufficient soluble soap present to form a lather on the surface of the sample.

The soap test for hardness gives a rapid determination of the maximum scale-forming possibilities of a feed-water. Not all the salts which form insoluble soap are scale-forming, but by assuming them to be scale-forming the operator provides himself with a slight factor of safety. This the boiler operator should know well and appreciate: if there is zero hardness in the boiler-water, scale cannot be formed in the boiler.

The treatment of boiler-water for the prevention of scale and the consequent achievement of zero boiler-water hardness, may be accomplished in a variety of ways. One of the oldest, and that which was used by the Navy for many years, is treatment with carbonate.

The carbonate for treatment usually is supplied as soda ash, anhydrous sodium carbonate, one of the cheapest of commercial chemicals. If sufficient carbonate is present the incoming calcium salts are converted to insoluble calcium carbonate and calcium scale is prevented. Part of the sodium carbonate in solution, under the influence of heat, is converted to sodium hydroxide and carbon dioxide.

(7) $Na_2CO_3 + H_2O \rightarrow 2\ NaOH + CO_2$

The sodium hydroxide combines with the magnesium salts to form insoluble magnesium hydroxide.

(8) $2\ NaOH + MgCl_2 \rightarrow 2\ NaCl + Mg(OH)_2$

The difficulty with carbonate treatment is the maintenance of a sufficient concentration of carbonate ion to combine with all cal-

cium. The decomposition of the carbonate shown in Equation 7 proceeds at a fairly rapid rate. In shore stations the carbonate can be fed continuously, but such an arrangement is not very satisfactory on ship board. Increase in operating pressure and in rates of evaporation increases the rate of decomposition and the difficulty of obtaining complete protection. In general, straight carbonate treatment, intermittently fed, is not satisfactory for boilers operating in excess of 150 pounds working steam pressure.

The use of sodium aluminate which has for some time been advised for the external clarification of shore waters, recently has been advanced as an internal treatment. In general, aluminate is used in conjunction with carbonate or phosphate. It has decided benefits in clarification of the boiler water and is of value in the treatment of waters high in magnesium salts. It is also used for the removal of silica in the prevention of silicate scales.

Silicates have been used with some success in the treatment of boiler-waters. The calcium and magnesium silicates are quite insoluble, but also they form some of the hardest and most immovable of scale deposits. Because of the variation in composition of the silicate salts, it is difficult to obtain very reliable data on their solubilities. Particularly is this difficulty noticeable in boiler-waters where the variation in alkalinity and concentration, together with the great number of different ions present, make possible the formation of an almost innumerable series of silicate salts. Sodium silicate, water glass, has been used with some success for the prevention of scale in sea-water evaporators. Because of the general uncertainty of results, however, the use of silicate should not be undertaken before careful experiments have shown it to be desirable.

One of the oldest chimeras pursued by boiler operators has been the belief that a metal surface can be made so smooth that scale cannot stick to it. Great numbers of coatings for boiler tubes have been advanced, used and forgotten. Boiler compounds containing a secret substance that penetrates the scale, coats the tube, and removes the scale have come and gone. It is now known that the formation of scale depends not upon the nature of the surface, but upon its temperature. When water is evaporated each bubble will leave its ring of scale crystals which must be dissolved off, but the ring will not fall off because the surface is smooth.

The most recent method of treatment is the colloidal system. A colloid is a tiny particle of a size somewhere between molecular and microscopic. These minute particles become attached to the scale-forming salts and carry them down as a very fluid sludge or gel. All manufacturers of colloidal treatments incorporate a certain proportion of recognized treating chemicals, such as soda ash or tri-sodium phosphate, in their mixtures. Such small quantities of these mixtures are used, however, that not all the beneficial action of the colloidal treatment can be ascribed to the inorganic material. Some of the colloids combine chemically to form insoluble calcium and magnesium salts. But again the quantities used generally are too small to account for all the protection received. As yet the colloidal methods are not susceptible to the same exact control as are the older, more established methods. While the colloidal method has virtue, it still must be classed as experimental.

Phosphate treatment is the last to be discussed. In alkaline solution the heavy-metal phosphate-salts are almost completely insoluble. The continuous maintenance in the boiler water of a fairly low concentration of phosphate ion will insure the absence of scale. Treatment with phosphate appears to be the best available method of scale-prevention. The most serious disadvantage of phosphate treatment is the possibility of the formation of feed-line deposits. The reaction of the phosphate with the scale-forming salts to form insoluble phosphates is so rapid as to be almost instantaneous. Where the phosphate is fed continuously into the feed water the insoluble salts are precipitated before they reach the boiler. The result is incrustation in the feed lines, and plugged tubes in feed heaters. This difficulty can be avoided by feeding a phosphate solution directly to the boiler drum or feeding in large, intermittent slugs. The heavy phosphate sludge is difficult to remove, and has a tendency to collect in the mud drums and in the tubes where circulation is slow. This condition can be alleviated by the use of some material to make the sludge more fluid or by increasing the alkalinity of the boiler-water. A mixture of carbonate and phosphate sludge seems to pack less than phosphate alone.

The Navy has adopted for use in boiler-water treatment a mixture of anhydrous disodium-phosphate and soda ash. This form

of phosphate has a slight advantage in cost, but, more important is the fact that a compound made up with it is about sixty per cent more concentrated than the equivalent compound made with tri-sodium-phosphate, the most common form of phosphate. It is possible to use a single compound because of the generally uniform conditions experienced throughout the Service, in which all vessels distill sea water for make-up. The proportions are so balanced that the phosphate is more than sufficient to care for the scale-forming salts, while the soda ash provides the alkalinity necessary to neutralize the unavoidable contamination of acid sea water. The carbonate also provides a second line of defense against scale formation. Some corn starch is mixed with the carbonate and phosphate. Its principal purpose is to increase the fluidity of the phosphate sludge.

Naval personnel who understand the nature of scale formation and the means for its prevention, by using the compound provided, should be successful in their efforts to maintain clean boilers. If at any time the means available become insufficient they should be able to make such an informative report as will bring promptly the aid required.

Unfortunately, when a clean boiler has been achieved, the cares of the operator are not at an end. There still remain the problems of carry-over and of corrosion. An exposition of the present knowledge of the theory of the cause and prevention of carry-over by foaming and priming will be given next. The final part of this article will be a similar discussion of corrosion.

BOILER-WATER CARRY-OVER BY PRIMING AND FOAMING.

Contamination of steam by carry-over of boiler-water may occur in three ways. The first way is by foaming, the second is by priming, and the third is by a combination of both foaming and priming. The terms "foaming" and "priming" will be defined for the purposes of this article because they have been used loosely, and to some extent interchangeably, by writers on the subject. An appreciable time is required for steam bubbles to burst after they reach the surface of the boiler-water. If the bursting is delayed, a layer of bubbles will build up on the water surface. When the bubbles are sufficiently stable, the layer of bubbles, or foam, may

extend from the water level to the dry pipe. In such a case water is carried over with the steam by foaming. Priming is the throwing of particles of water into the steam space by the violence of ebullition. It occurs when the rapidity of evaporation is so great that the flow of steam carries along the spray from the bursting bubbles, or when the bursting is of such violence as to throw particles of water high into the steam space. While it is difficult to diagnose a case of boiler-water carry-over as a specific case of one or the other, the difference between the mechanics of the two is readily discernible.

The research of Professor C. W. Foulk of Ohio State University has shown that foaming is a surface phenomenon. It long has been known that many properties of liquid surfaces differ from the same properties of the body of the liquid. Within a solution there are latitude and freedom for the relief and balancing of all ionic and molecular stresses. Within the surface, a layer only one to three molecular diameters in thickness, these stresses can be relieved in only one direction, on the side toward the body of the solution. This unbalance of stresses results in some anomalies in the physical and chemical behavior of the surface.

The surface phenomenon which affects foaming is the surface concentration. The concentration of dissolved salts is uniform throughout the body of a solution, but in the surface the concentration may be greater or less, depending upon the salts present. A salt which is present in greater concentration in the surface than it is in the body of the solution is called "positively absorbed." Similarly, a "negatively absorbed" salt will tend to leave the surface so that the concentration in the surface will be less than that in the body of the solution. The surfaces, and the difference between positive and negative absorption, are illustrated in rather exaggerated form in Figure III.* Only in pure liquids, without any dissolved solids, is the concentration in the surface the same as that of the rest of the solution.

The bursting of a steam bubble is effected by the gradual approach to each other of the inner surface of the bubble and the upper surface of the boiler-water. When these two surfaces

* Figure III has been copied from an illustration in an article by C. W. Foulk and J. N. Miller which appeared in the November, 1931, issue of Industrial and Engineering Chemistry.

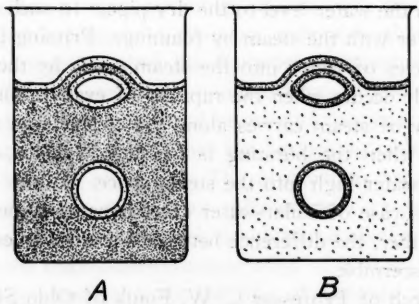


FIGURE III.—DIAGRAM OF DIFFERENCE BETWEEN NEGATIVE AND POSITIVE ABSORPTION.

A represents the solution of a negatively-absorbed salt. The concentration in the surface is less than in the body of the solution. B represents the converse-positive absorption.

merge, the bubble bursts. This is illustrated by the successive steps shown in Figure IV. As soon as the bubble rises above the water level, solution begins to drain away from between the two surfaces. The solution drains out and the surfaces approach each other until the buoyant effect of the steam is sufficient to rupture the retaining film with its inner and outer surfaces. The released steam merges with that in the steam space, while the solution in the film drops back into the boiler water. The height to which the bubble will rise through the surface before rupture occurs depends upon the size of the bubble and upon the strength and stability of the film.

There are two opposing forces in the passage of steam bubbles through the liquid surface. They are the upward force of the

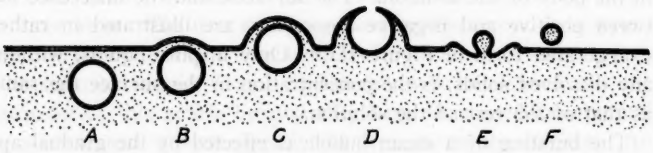


FIGURE IV.—SUCCESSIVE STEPS IN THE BURSTING OF A STEAM BUBBLE.

A to C represent the progressive thrusting of the bubble through the surface. D illustrates the condition of the bubble at the moment when it is ruptured, before the liquid sides have dropped back into the water. In E the sides have fallen into the water forcing up a ball of water in the center of the crater. At F the ball of water has been thrown above the surface, whence it either will drop back or will be carried along with the steam.

bubble caused by its displacement of the denser solution, and the restraining force of the two surfaces. The upward force is relatively simple, since it amounts to the difference in weight between that of the steam in the bubble and that of the solution which it displaces. The restraining force is composed of two factors; the strength, and the stability of the surface. The strength of the surface can be measured by a determination of the surface tension. The magnitude of the surface tension affects the size of the bubbles, but experiments with a variety of pure liquids has shown that it has little influence on the formation of foam. Evidently the upward force of the bubble is greater than the surface tension. The controlling force therefore is not the strength, but the stability of the surface.

The stability is the result of the difference in concentration between the surface, and the body of the liquid. As the bubble thrusts itself through the level of the liquid, solution begins to drain from between the two surfaces. The force which maintains a different concentration in the surfaces resists this drainage, because when the drainage is completed the surfaces must merge and the bubble must break. If the force for maintenance of the surfaces is sufficiently great, the bubble does not break, but remains floating on the surface. More bubbles are thrust upward by continuation of the evaporation so that a blanket of bubbles, in other words a foam, covers the water surface in the boiler.

The solution between the two surfaces surrounding a bubble of foam is not separated from the main solution but constitutes a liquid envelop or band that extends upward from the solution around the bubble and back into the solution. If there is a second layer of bubbles on the water surface the connection with the solution still remains unbroken. However, as the level of foam is thrust higher into the steam space the tendency of the solution to drain from between the surfaces increases. An increased stability of the surfaces is required to maintain the foam. Eventually the stability of the surface is insufficient and the bubbles in the topmost layer break.

Pure liquids do not foam but all solutions foam to a greater or less degree. The extent of the foaming depends upon the stability of the surface induced by difference in concentration be-

tween the surface and the body of the liquid. This difference increases as the total concentration increases. The carry-over of water by foaming can be prevented by maintaining such a low surface stability that a layer of foam cannot be built up.

There are two methods for the decrease of surface stability and the prevention of foaming. The first, and most common, method is to reduce the total concentration of the boiler water, in other words, to blow down the boiler. The method is both expensive and inconvenient. It is inconvenient and often is impossible to blow down without seriously interfering with the ship's schedule, since carry-over occurs when the boiler is operated at a high rate of evaporation. The other method is to neutralize the stabilizing salt or salts. Neutralization is possible because there are both positively-absorbed and negatively-absorbed substances.

The foam caused by a negatively-absorbed substance may be destroyed by the addition of a positively-absorbed substance. Most of the common, inorganic salts which occur in boiler-water are negatively-absorbed. In general, foaming of boiler water can be reduced or prevented by the addition of a substance which is strongly, positively-absorbed. There are many positively-absorbed substances which may be used; corn starch, which is included in Navy Boiler Compound 1933, is one such substance.

In addition to the dissolved salts in boiler water, the suspended solids also affect film stability. Particles in suspension may be positively or negatively absorbed in the surface films. Possibly carry-over from this cause might be accomplished by the addition of suitable solid material to neutralize the effect of the positively or negatively absorbed solids which were stabilizing the foam. However, this phase of foaming has not been so completely investigated as that of stabilization by salts in solution, so that the safest plan is to remove the troublesome solids by blow down.

Priming is almost entirely a matter of boiler design. As each steam bubble breaks a small drop of water is thrown upward. This drop is forced up from the crater left by the broken bubble as the sides rush down to water level. Rapid evaporation will produce a considerable spray of water particles. If the water level is too high, or if the boiler drum is not carefully designed, the rush of steam may carry this spray into the dry pipe in such

quantity that it cannot be separated from the steam. With the combination of rapid evaporation, high water-level, and a small steam drum, it is possible for the dry pipe to be drenched by the water thrown upward. In such cases carry-over is most severe.

Under some conditions of boiler water and of evaporation it is possible for steam ebullition to be so violent as to be almost explosive. At such times large volumes of water may be thrown into the steam space as an almost unbroken mass. Reduction of the rate of evaporation is the only remedy for such conditions. However, this occurrence is of such rarity as not to be a serious problem.

An understanding of the causes of carry-over provides a means for its prevention. Because the susceptibility to priming is increased by the ship's motion, protection against carry-over must be more complete on shipboard than is necessary in shore plants. Steam drums are made as small as possible because of space and weight limitations, and the steam space accordingly is reduced. In addition, the ship's motion induces waves in the boiler-water. Vertical baffles are installed to break up longitudinal waves, but these give only partial protection. Complete protection can be attained only by careful control of the boiler-water conditions combined with the mechanical control of the water level.

The maintenance of a low concentration is the principal protection against carry-over. The present maximum limits for salinity, which is the indicator of total concentration, have been determined from the results of long experience. They are intended as conservative limits, low enough so that satisfactory operation can be maintained under adverse conditions. However, a great deal must be left to the discretion and judgment of the Engineer Officer. A boiler which can be operated satisfactorily at a high rate of evaporation in fair weather, with water having a hundred grains per gallon of chloride, may not be able to hold a ten-pound rate of evaporation in a heavy sea, if the water has more than a fourth as much chloride. It is a common practice in shore plants to increase the concentration until water carries over, and thereafter to maintain the concentration safely below the determined, dangerous level. An Engineer Officer may use such an indicator if he interprets it in the light of his experience. The amount of suspended solids in the

water is a further cause of carry-over by foaming. Boilers from which quantities of scale are being removed by new treatment or overtreatment with compound, generally have dirty water. The loose scale is suspended in the water and must be removed before it reaches a dangerous concentration. The amount in suspension may be determined by centrifuging a measured sample of the water in a graduated tube. Apparatus for such a determination are available in the sick bay of most ships. No definite limit can be set, but, in general, more than three-tenths of a per cent of solids by volume may be considered undesirable.

Boiler-water salinity may be controlled both by prevention of feed-water contamination and by blowdown. Blowdown is the only means for the removal of suspended solids. The prevention of contamination of boiler feed-water has been discussed in the second part of this article; removal of contamination from boiler-water is a simple, although expensive, matter.

The method of giving the blowdown is important. No more water should be wasted than is necessary because of the heat loss involved. The surface blow should be used if it is desired to reduce the salinity. The water in the steam drum, which has just passed upward through the tubes, is more concentrated than water elsewhere in the boiler; so that the same amount of salts can be removed with less water from the steam drum than from the mud drum. If suspended solids are to be removed, the boiler first must be taken off the line. As the solids settle in the boiler water, short bottom blows should be given at intervals of fifteen to thirty minutes, until enough solids have been removed. In case the boiler cannot be removed from the line the surface blow should be used for suspended as well as for dissolved solids.

An additional safeguard against carry-over has been provided by the recent increase in the proportion of starch in the boiler compound. Starch is positively absorbed and thus tends to neutralize the foam-stabilizing properties of the negatively-absorbed inorganic salts. The judicious control of the concentration of dissolved and suspended solids, combined with the maintenance of recommended alkalinities, should make carry-over extremely rare in the Naval Service.

It has been shown that scale-formation and carry-over, with their attendant damage to machinery and efficiency, can be prevented. A third problem of boiler operators is the prevention or control of corrosion. As in the foregoing parts of this article, the theories of the problem will be discussed first, followed by a presentation of the means available to Naval personnel for the reduction and avoidance of corrosion.

OCCURRENCE AND REDUCTION OF CORROSION.

There are three important theories which seek to explain the corrosion of boiler metal. All three have been established by careful experiments, but no one of the three is a complete explanation by itself. The first is the acid theory, the second is the electrolytic theory, and the last is the theory of differential aeration. They will be considered in that order.

According to the acid theory, corrosion is the result of an acid dissolving the metal. This action is easily understandable because of the readiness with which iron dissolves in strong acids. The reaction of iron with hydrochloric acid is an example.

$$(9)\quad Fe + 2\,HCl \rightarrow FeCl_2 + H_2 \uparrow$$

When a piece of iron is dropped into a solution of acid the evolution of bubbles of hydrogen is apparent immediately. In a slightly acid boiler-water the gradual solution of iron would be expected.

However, acidic corrosion may occur even in slightly alkaline boiler water. In the parts of the boiler where water circulation is imperfect, the alkalinity may be somewhat lower than in the parts where the water is more rapidly circulated. This is particularly true in boilers where the feed-water is not mixed promptly and thoroughly with the rest of the boiler water as soon as it enters. Some salts upon dissociation give an acid reaction. Magnesium chloride is an example.

$$(10)\quad Mg\,Cl_2 + 2H_2O \rightarrow Mg^{++} + 2Cl^- + 2H^+ + 2OH^-$$

Magnesium hydroxide is quite insoluble so that it precipitates, leaving the other ions in solution.

$$(11)\quad Mg^{++} + 2Cl^- + 2H^+ + 2OH \rightarrow Mg\,(OH)_2 \downarrow + 2H^+ + 2Cl^-$$

The effect of two hydrogen and two chloride ions is the same whether they are derived from magnesium chloride or directly from hydrochloric acid. The reaction of equation (9) then occurs, and boiler steel dissolves.

The maintenance of a sufficient alkalinity insures the removal of all acid salts and so provides protection against acidic corrosion. The destructive effect of such salts as magnesium chloride may be neutralized instantly by sodium hydroxide.

(12) $Mg\,Cl_2 + 2Na\,OH \rightarrow Mg\,(OH)_2 \downarrow + 2Na\,Cl$

Sodium chloride is a neutral, non-corrosive salt, and the magnesium hydroxide is precipitated and removed from further activity.

The electrolytic theory explains corrosion as the result of the action of many tiny cells or couples. No two metals have the same electrical potential, so that when a pair of dissimilar metals are immersed in a solution, an electric current flows from one to the other. As a result the more electro-negative, or baser, metal will tend to go into solution, while the more electro-positive, or nobler, metal tends to separate from solution. A very slight difference in potential will induce the flow of a current, which will be correspondingly small. The danger is that the effects of each cell are concentrated in a small area, and even a very slight current, when continued for weeks and months of boiler operation, can develop quite a sizeable pit.

In general, the rate of electrolytic attack is cumulative. The corrosion products are more noble than the iron. As they are deposited they seal the mouth of the opening so that inside of the pit the rate of attack is accelerated. For example, since mill scale is electro-positive to iron, it will be less liable to attack than pure iron. However, at any small crack or break in the mill scale coating the iron will be exposed and a cell will be set up. Current will flow from the iron to the mill scale and gradually the crack will be filled with iron oxide or iron hydroxide, both of which are more noble than iron. Beneath the plug of oxide or hydroxide the attack of the iron will continue as long as the electro-deposited iron can be oxidized.

Highly stressed iron is electro-positive to unstressed metal. Improperly drawn or rolled tubes, rivet heads, or the metal in riveted

joints may become positive poles in cells which gradually destroy the normal metal in the immediate vicinity. Any irregularity in the boiler metal may be the cause of the destruction either of itself or of adjacent metal.

There are two means of protection against electrolytic attack. The first is the provision of a perfectly homogeneous metal surface. If this ideal could be obtained no other protection would be necessary, but since it only can be approached, other protection must be provided. The other method of protection is the elemination of oxygen from the boiler water.

The various metallic differences and non-homogeneities are the cause of local differences in electrical potential, but without a supply of electrons there can be no flow of current and no corrosion of the boiler metal. The supply of electrons may come from stray electrical currents, but it usually comes from oxygen which enters with the feed water. The molecular oxygen which is dissolved in the water has an equal number of positive and negative charges, which may be designated thus $(^{++}O^{--})_2$. When neutral, dissolved oxygen approaches one of these minute electrical couples each atom becomes negatively charged and gives up two positive charges. These charges are seized by the iron, which goes into solution as tervalent iron, Fe^{+++}. Each ion of iron combines with three hydroxyl ions to form a molecule of ferric hydroxide, which precipitates. Here again the cell action would stop if there were not a continuing supply of oxygen. The following equations illustrate the sequence of events.

(13) $3\ (^{++}O^{--})_2 + 4\ Fe \rightarrow 4\ Fe^{+++} + 6\ O^{--}$

(14) $H_2O \rightarrow H^+ + OH^-$

(15) $Fe^{+++} + 3\ OH^- \rightarrow Fe\ (OH)_3$

Combining and balancing the above three equations gives this result.

(16) $3\ O_2 + 4\ Fe + 6\ H_2O \rightarrow 4\ Fe\ (OH)_3$

From this it may be seen that the amount of oxygen is directly proportional to the amount of iron corroded from the boiler metal.

The differential-aeration theory is an extension of the more general electrolytic theory. It aids in the explanation of the rapid-

ity of attack in the bottom of a corrosion pit. If two identical pieces of metal are immersed as electrodes in a solution, connected electrically outside of the solution, and a stream of air or oxygen allowed to bubble up past one of the two electrodes, a small electrical current can be generated. The aerated electrode is more positive, so that metal dissolves from the unaerated one.

If there is oxygen in the boiler-water, it is obvious that its concentration will be greater in the water than at the bottom of a pit, the mouth of which is partly stopped by a precipitate of ferric hydroxide. As a result of the difference in the aeration of the surfaces the normal cell action will be accelerated. However, it is doubtful whether the total concentration of oxygen in the boiler water can be sufficient to have a very great influence on corrosion by means of differential aeration.

A rather specialized type of boiler metal corrosion is that commonly known as caustic embrittlement. The name is derived from the similarity between the crystal structure of fractured metal from embrittled boilers and that from iron pots used for boiling caustic soda. The fracture of embrittled metal is characterized by inter-crystalline instead of trans-crystalline cracks. While such cracks are common in iron vessels which have been exposed to high concentrations of hot caustic, such conditions do not occur in boilers.

However, it appears possible for local concentration of boiler-water to occur. In microscopic fissures, at seams or under rivet heads, a small quantity of water may be concentrated to many times the alkalinity of the boiler water. These fissures cannot be prevented completely, although very careful fabrication and avoidance of outside caulking will minimize their occurrence.

The best means now available for the prevention of caustic embrittlement is similar in character to the method for scale prevention. Since concentration of boiler-water in fissures cannot be prevented, the water should be so treated that when it is concentrated it remains harmless. This is accomplished by keeping enough sulfate in the water so that before a dangerous concentration of caustic soda is reached sodium sulfate will percipitate. The sodium sulfate acts as a protective coating on the iron and prevents the attack of caustic.

There are two sorts of external corrosive attack of the boiler metal in addition to internal corrosion. At high temperatures iron will combine directly with oxygen to form magnetic oxide, Fe_3O_4.

(17) $3\ Fe + 2\ O_2 + \text{heat} \rightarrow Fe_3\ O_4$

This type of corrosion should not occur in a properly operated boiler. It can result only from delayed heat-transfer from the metal to the water. This delay in turn may be caused either by the presence of an insulating layer of scale or by an impediment in the water circulation. Information is available as to the avoidance of either of these difficulties.

Acid corrosion of the outside of boiler tubes occurs frequently. Fuel oil contains considerable sulfur, much of which is transferred to the outside of the boiler tubes by the process of combustion. The slag which accumulates on the outside of the boiler tubes has a large percentage of sulfur in such an oxidized state that when moistened it yields dilute acids. These acids in turn attack the tube metal. If the furnace is kept dry this damage to the tubes may be avoided. Stacks of idle boilers always should be covered.

Before the digression to a discussion of external corrosion, the various theories of internal corrosion were presented in turn. Although all three forms of corrosion can occur simultaneously the prevention of corrosion is not thereby made more complex.

The first, and most important, step is to maintain continuously a satisfactory high alkalinity. It is doubtful whether a normal alkalinity of less than 0.4 per cent will prevent all corrosion by acid salts. Certainly it provides little reserve of protection against a sudden access of sea water contamination. However, it is inadvisable to exceed an alkalinity of 0.7 per cent normal as a precaution against caustic embrittlement. Electrolytic attack can be minimized by maintenance of a moderate alkalinity and the increased rapidity of electrolysis in acid solution can be avoided by the same means.

A suitable arrangement and preparation of the boiler drum and fittings is a sound preventive measure. All metal of the drum, tubes and fittings should be similar to avoid the induction of electrolytic cells and couples. The arrangement of internal baffles should be such as to prevent dead pockets. Tubes should not be

overrolled, but should be fitted carefully to avoid excessive stress in the metal. The removal of all mill scale from the boiler interior is advisable. Altogether, all inside surfaces of the boiler should be as homogeneous, and the boiler-water should be as nearly perfectly mixed, as possible.

The final and most important effort must be made to avoid oxygen contamination. There are three ways, which are within the means of the personnel of any ship, in which this may be accomplished. The first step is the deaeration of make-up feed-water. During the time that water is stored in bottoms there is opportunity for it to become almost completely saturated with air. Unless this air is removed the water will carry five or six milliliters of air per liter instead of the two or three-tenths of a milliliter which are contained by deaerated water. This excess of four to five or more milliliters of oxygen per liter can be removed by taking all make-up feed-water through the condenser, where it is subjected to a vacuum of twenty or more inches, and thence discharging it to the hot well.

The hot well itself must be protected against oxygen contamination. The most potent source of oxygen contamination of water in the hot well is a cascade discharge from the filter box or loofa sponge compartment. Water which is as nearly free of air as mechanical devices can make it, here is sprayed through the air for a distance of two to six feet. By the time the water reaches the surface of the hot well it is virtually saturated, and a considerable effort for deaeration has been wasted. A drowned-tube discharge from the last compartment of the filter box to the bottom of the hot well will prevent oxygen absorption. As an additional safeguard against absorption of air at the water surface, the level should be maintained as nearly constant and as undisturbed as possible. All drains leading to the hot well should be carried clear to the bottom. The temperature of the water in the hot well should be maintained as high as possible.

Even if all the precautions that have been outlined are followed a small concentration of oxygen will remain in the boiler feed-water. The internal fittings of the boiler should be so arranged as to minimize the possible damage from oxygen corrosion. If the internal feed pipe is installed so that the feed water is dis-

charged downward into the upper ends of the downcomers, a very common arrangement, the full effect of the oxygen will be expended on the first few feet of the downcomers. In this area accelerated attack will occur and the time of failure will be hastened. The proper arrangement is to discharge the feed-water upward into or through the water surface so that there will be an opportunity for the air to escape and be swept out with the steam.

The theories of scale-formation, carry-over and corrosion have been discussed and the means available for protection against these boiler troubles have been presented. The necessary precautions may be summarized briefly.

Boiler scale may be prevented by the maintenance of zero hardness, together with a phenolphthalein alkalinity of 0.4 to 0.7 per cent normal, in the boiler-water. Existent scale may be removed gradually by the same treatment The rate of scale removal may be increased by increasing the alkalinity of the boiler-water, together with the use of frequent, periodic blowdown. After each blowdown, enough compound should be added to replace the alkalinity removed by the blow.

The concentration of dissolved and suspended solids must be kept below dangerous values to avoid carry-over of the boiler-water. Access of solids to the boiler may be prevented by the avoidance of feed-water contamination. Once the solids reach the boiler, blowdown is the only remedy. The concentration of dissolved solids is proportional to the salinity, or chloride concentration, which is used as an index. Suspended solids may be determined by centrifuging a measured sample of boiler-water.

The primary means of protection against corrosion of boiler tubes and shells is the elimination of oxygen from the feed-water. After the oxygen content of the feed-water has been reduced to a practical minimum, further protection may be attained by the proper arrangement of the internal feed-lines and baffles of the boiler. The maintenance of a suitable alkalinity of the boiler-water is the last line of defense against corrosion.

PARALLEL OPERATION OF SINGLE STAGE BOILER FEED PUMPS.

By Lieutenant Commander H. J. Redfield, U. S. N.

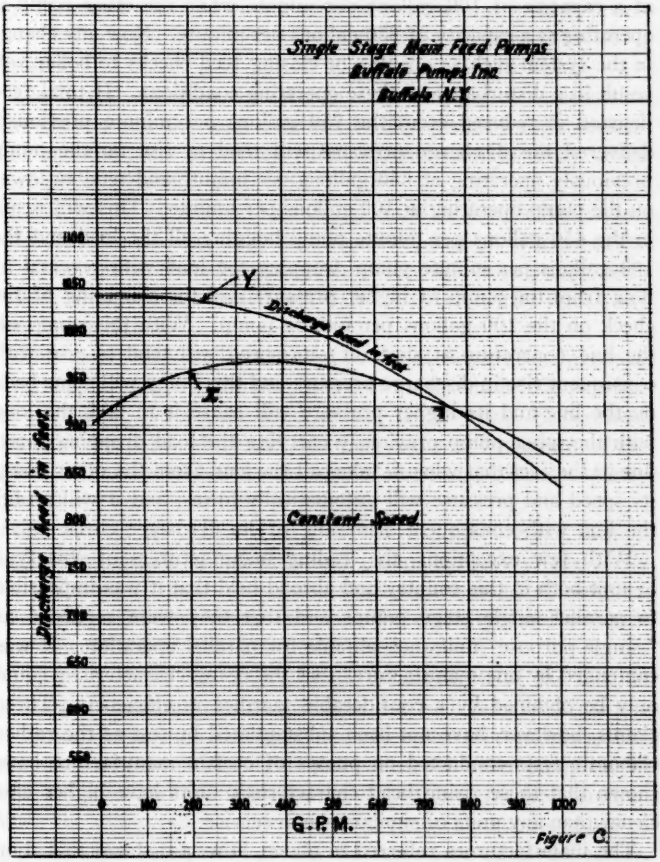
Several articles* appearing in this publication have indicated the numerous advantages of the high speed single stage centrifugal boiler feed pump for naval use. Pumps of this type were specified and obtained for heavy cruisers 24 to 31 having a head-capacity characteristic which was practically flat from the rated capacity (750 gallons per minute) to shut off. Actually these units showed a slight droop at shut off or zero capacity. (See Figure C, curve X).

The original idea in using flat characteristic pumps, proposed that by a flat characteristic no pressure regulating governor would be necessary since the pump would maintain a constant head at constant speed regardless of the capacity. This idea is perfectly sound and pumps having a flat characteristic actually demonstrated that no pressure regulating governors are required where paralleling is not necessary.

As soon as parallel operation was attempted, however, these units showed that parallel operation especially at lower capacities, was extremely unstable and violent surging of the units and slamming of the check valves occurred. This surging or see-sawing (first one pump taking practically all the load and the other pump dropping the load and vice versa) and slamming of checks results from the fact that with two pumps with so-called flat or drooping characteristics discharging into a common main, there are no factors existing in the installation which will influence the pumps to operate on a fixed point of their head capacity curve when the combined output or capacity is constant. It should be remembered

* (1) The Coffin High Speed Boiler Feed Pump, by Lieutenant Commander T. A. Solberg, February, 1929, Journal A. S. N. E.

(2) Worthington Single Stage Centrifugal Pump, by J. B. Lincoln, Mechanical Engineer, U. S. Naval Experiment Station, May, 1927, Journal A. S. N. E.



that the discharge pressure is the only common controlling factor for two pumps operating in parallel, and with a flat characteristic pump such as curve X, Figure C, it will be noted that for any speed two widely different capacities may be obtained while operating at a fixed discharge pressure.

Thus it will be noted from Figure C, curve X, that at constant speed and discharge pressure of 945 feet one pump may operate

at a capacity of 100 gallons per minute while the other pump is operating at a capacity of 650 gallons per minute. Now any change in the system such as opening or closing feed checks to boiler will result in a disturbance of these operating conditions. If total feed demand is reduced from the 750 gallons per minute previously delivered the discharge pressure will tend to rise on the pump previously operating at 650 gallons per minute and tend to lower on the pump operating at 100 gallons per minute. This will result in the 650 gallons per minute pump hogging all the load and the 100 gallons per minute pump dropping the load with reversal of flow from the pump of higher pressure and the slamming of the check on the 100 gallons per minute pump. With this pump off the line (operating at shut off) its speed will tend to rise with consequent rise in discharge pressure and this pump will come back on the line and its higher pressure will cause it to take the load with the other pump previously carrying the load dropping same, due to the fact that when it takes all the load from the other pump its speed and pressure will automatically lower, and it will go off the line with consequent slamming of its discharge check valve.

With few exceptions, the leading manufacturers of this type of unit both in this country and abroad held that it was impossible to parallel single stage pumps and that they were regarded as "single purpose" units not suitable for parallel operation. It was contended by one manufacturer that the rising characteristic could only be obtained by a considerable sacrifice in efficiency. These claims, however, have not been substantiated by test as the rather elaborate tests conducted on pumps of certain manufacture have shown that these rising head characteristic units have higher efficiency than any units of similar type in service.

The manufacturers referred to above, however, stated that they could furnish new impellers for the units they had in service such that the "flat" characteristic would be changed to a uniformly rising characteristic and that with the new impellers their pumps would parallel at any capacity.

A uniformly rising head characteristic pump presents no difficulties for parallel operation because for any given condition at constant speed, there is only one point at which the pump can possibly operate. Curve Y, Figure C, shows the rising head-

capacity curve obtained by a change in impellers on pumps previously having a flat or drooping characteristic as shown on curve X, Figure C.

The Bureau accepted the offer of this company to demonstrate their claims, and the tests conducted fully justified their contentions and the units concerned paralleled very satisfactorily under all possible operating conditions.

Faced by the established fact that it could be done, other manufacturers have developed modifications such that all cruisers originally having flat characteristic pumps soon will have pumps with a rising characteristic which will parallel satisfactorily under any capacity condition.

Units essentially similar to those on the earlier cruisers are now being supplied and it is the purpose of this article to briefly describe the paralleling tests conducted at the Engineering Experiment Station, Annapolis, Maryland, on these units as indicative of the results to be expected from the operation of rising head capacity boiler feed pumps operating in parallel.

The test set up consisted of two No. 5½ Class SFU Buffalo single stage double inlet boiler feed pumps driven by type BAN Terry Turbines. Each pump was fitted with a standard commercial horizontal swing check valve on the discharge and a 3-inch Swartout SC excess pressure pump governor.

Figure A shows the diagrammatic arrangement of the test set up using a separate pressure governor for each pump. With this set up satisfactory paralleling is obtained under all conditions. As one pump was cut out by its throttle valve, the other pump would assume the entire load immediately without any marked hunting. When the idling pump was cut in each pump assumed a share of the load immediately without any fluctuation or other difficulties.

To obtain load equalization, however, it is necessary to have equal excess pressure governor settings. The water actuating lines to the excess pressure governors may be cross connected for slightly improved load equalization characteristics. This set up permits, if desired, running one or more units at full capacity and controlling on another unit.

Figure B shows the diagrammatic arrangement using one excess pressure governor to control two units. Any pumps of similar

characteristics will parallel with equal loads at all times with this system of regulation since in effect it gives equal steam chest pressures on the turbines and forces the pumps to run at a fixed point on their head capacity curves.

For units located in different compartments this set up would involve too much piping and if four units were actuated by a single excess pressure governor the accuracy of regulation at partial loads would probably be poor. The cross connecting of the pilot valves on Leslie or Foster regulators in effect is identical to one excess pressure governor controlling two or more units because it assures equal turbine steam chest pressures on both units at all times. This method necessitates load equalization at all times and it is impossible to operate one or more units at full capacity and control with one unit where pumps are thus connected.

It was originally intended in connection with this paralleling test to determine the effect of different types of check valves on the paralleling of the pumps. Certain manufacturers stated that the difficulty in paralleling was caused by the check valves. Various types of balanced non-return and cushioned checks were proposed to eliminate the difficulties. However, results of later tests have indicated that the conventional swing check valve is entirely satisfactory with a pump of the correct characteristics and the drop across this type is about one-tenth the drop across the cushioned vertical lift type. The complications therefore of the "balanced" or cushioned type of check valve do not appear to be justified as there is no necessity for other than the simplest type.

Further, with the cushioned checks, in cutting out a pump the check valve will tend to "hang open" until a considerable back flow through the pump being cut out takes place. This results in an appreciable drop in pressure on the discharge main and when the cushioned check does close a water hammer is set up in the piping. In the case of swing checks no such hang open exists and consequently no water hammer results.

An additional test with separate regulators for each pump was conducted with the actuating water for the excess pressure governors taken from the common discharge main beyond the check valves of the two pumps. This resulted in unstable operation, surging of the units and slamming of the check valves.

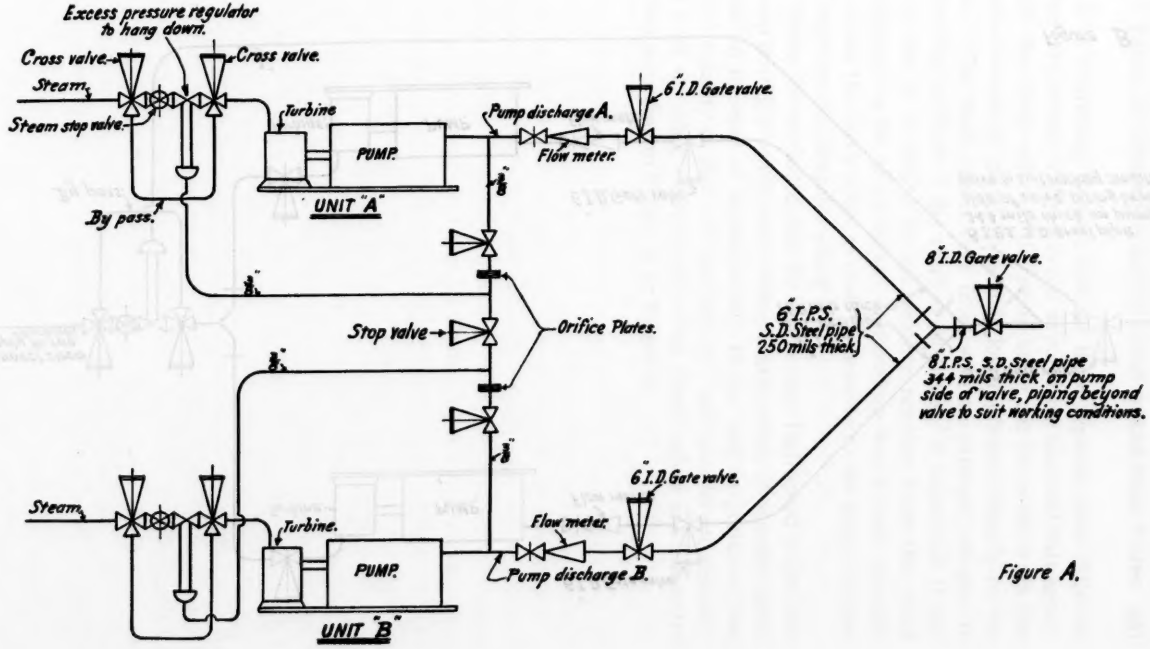

Excess pressure regulator to hang down.
Cross valve.
Cross valve.
Steam.
Steam stop valve.
Turbine
PUMP.
UNIT "A"
By pass.
Pump discharge A.
6" I.D. Gate valve.
Flow meter.
8" I.D. Gate valve.
6" I.P.S. S.D. Steel pipe 250 mils thick.
8" I.P.S. S.D. Steel pipe 344 mils thick on pump side of valve, piping beyond valve to suit working conditions.
Stop valve
Orifice Plates.
Steam.
Turbine.
PUMP.
UNIT "B"
6" I.D. Gate valve.
Flow meter.
Pump discharge B.

Figure A.

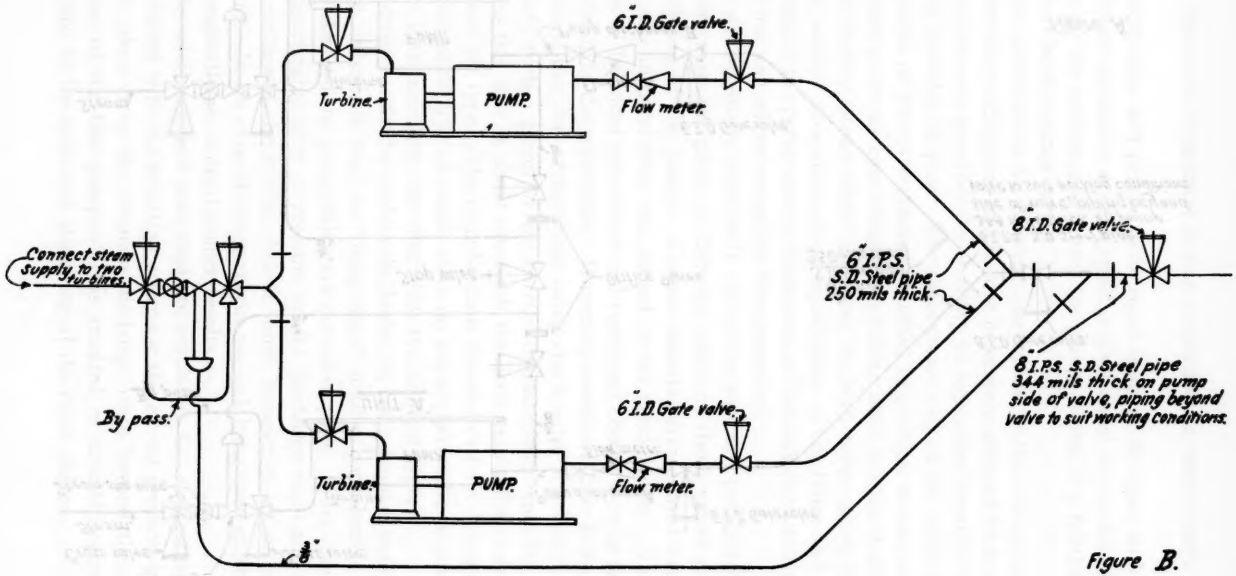

6" I.D. Gate valve.
Turbine.
PUMP.
Flow meter.
8" I.D. Gate valve.
Connect steam supply to two turbines.
6" I.P.S. S.D. Steel pipe 250 mils thick.
8" I.P.S. S.D. Steel pipe 344 mils thick on pump side of valve, piping beyond valve to suit working conditions.
By pass.
6" I.D. Gate valve.
Turbine.
PUMP.
Flow meter.
8"

Figure B.

It is interesting to note that on three separate tests different observers, among whom was the writer, have observed that apparently the check valve on the pump being cut in on the main line starts to open at about 15 pounds lower pressure than is on the line. The check valves were fitted with an external indicator to show the position of the valve at all times. It seems that if this is a fact, it is caused by the velocity reaction from the pump impinging on the check valve. It therefore would seem desirable to locate the check valve as close as possible to the pump diffuser to augment this desirable effect.

It may be concluded that the single stage high speed boiler feed pump having a continuously rising characteristic at constant speed with an increase of approximately 12 per cent in pressure from rated capacity to shut off (no delivery) will parallel satisfactorily in a set up using conventional swing check valves and connected either according to Figure A or Figure B.

EUROPEAN SYNTHETIC MOLDING SANDS.*

By C. W. Briggs, Member, and R. A. Gezelius.†

I. CHAMOTTE.

The American foundrymen, during the last few years, have seen and heard many references concerning the synthetic sands used in European foundries in the production of steel castings and, in view of the enthusiastic claims put forward by the users of these materials, they have considered these references with a certain amount of interest. It has long been recognized in this country that sand is one of the important variables in the manufacture of steel castings. Therefore, no foundryman can afford to permit his interest to lapse or fail to study current information concerning sands or sand research.

The American Foundrymen's Association has so thoroughly recognized this principle by devoting itself wholeheartedly to the study of foundry sands that it was not surprising to hear European synthetic sands mentioned several times during the last convention. The astonishing thing was that there was little or no actual data on the properties and characteristics of these sands presented.

The synthetic sand that has the greatest reputation in Europe is Chamotte. The name implies French origin, but the English have used the same material for many years though referring to it by other terms. Nevertheless, the term Chamotte now applies to this type of sand throughout Europe. One becomes quite interested in Chamotte when its virtues are enumerated. Chamotte, according to its proponents, prevents casting porosity, produces excellent casting surfaces, presents ideal molding conditions, a minimum amount of sand inclusions, cleaning troubles are at a minimum, and so on. In fact the claims make Chamotte the perfect molding material. These statements are not those of sales propaganda put

* Published by permission of the Navy Department.

† Division of Physical Metallurgy, Naval Research Laboratory, Anacostia, D. C.

forward by the manufacturers of Chamotte but they are the enthusiastic claims of the users, the manufacturers of steel castings.

What is Chamotte? Chamotte is a highly-aluminous clay that is roasted at high temperatures to make it very refractory. This clay is introduced into roasting ovens in 9-inch cubes and is roasted above 1500 degrees C. whence it breaks into pieces about the size of egg coal. After cooling it is ground to the required fineness. For molding, this calcined clay is mixed with a raw clay binder in the proportions of 85 per cent, by weight, of calcined clay and 15 per cent of raw clay. Upon the addition of water it is suitable for immediate use.

The analyses show that Chamotte varies somewhat. However, the three analyses in Table I are typical:

TABLE I.

Al_2O_3	37.50	31.75	42.69
SiO_2	56.46	63.50	54.78
Fe_2O_3	2.5	2.15	1.15
CaO	0.5	Trace	0.51
MgO	0.8	1.0	0.17
TiO_2	1.8	1.17	
Na_2O			0.25
K_2O			0.45

The point of fusion, cones Seger, is usually about 34 to 35 (1750 degrees–1770 degrees C. or 3180 degrees–3220 degrees F.).

In England, prior to the use of manufactured clacined clay for molding purposes, the old clay crucibles used in making crucible steel were ground and used in a manner similar to the Chamotte of today. In some places in England this method is still in use. At the Atlas Steel Works, Armadale, West Lothian, the molding sand is made up of ground crucibles and silica sand. Also, at the Vickers Armstrong Plant ground old crucibles, silica sand and clay are mixed together and used.

Captain Louis Shane, U. S. N., on his recent visit to the steel foundries of Europe for the Navy Department was so impressed with the many excellent properties he heard regarding Chamotte that he recommended that it be tested and used in the foundries operated by the Navy and if found to be successful that sand of

a similar nature be manufactured in this country for use as a molding material for steel castings. An amount sufficient for practical tests and observations was obtained from Establissements F. Labesse, an organization that manufactures a high grade type of Chamotte. The tests reported on herein were made from this material.

Chamotte as ready for use is quite granular. This is because the foundryman employs a sand whose grain size is from 5 to 2 millimeters in diameter. Calcined clay finer than 2 millimeters is removed before mixing with the raw clay.

The screen analysis in Table II shows the grain distribution:

TABLE II.

Screen No.	Per Cent	Screen No.	Per Cent
6	0		
12	20.2	100	1.09
20	54.3	150	.7
28	4.1	200	.6
35	1.56	270	.46
48	1.01	—270	.7
65	1.08	Clay bond	14.3

The most important feature in preparing the sand for molding is to carefully add the correct percentage of water. If the water is not measured the mixture may turn out to be a sticky mass that will be extremely difficult to mix and nigh impossible to mold. Water additions in the neighborhood of 5 to 8 per cent, according to the local conditions, appear to be the best to use. Mulling time can be varied, of course, to suit the foundryman's likes, however, 4 minutes mulling will be sufficient.

The permeability of the sand is very high being 2000 or greater in the green state. The dry permeability was unobtainable due to the fact that in using the core permeability tube the mercury ran through the test piece. Such an open sand would allow for the gases to escape quickly and easily. This feature the European foundrymen consider to be essential if the best results are to be obtained from a molding sand.

A study of Chamotte using varying water contents was made and the results are listed in Table III:

TABLE III.

	Water Content		
	5 Per Cent	6.9 Per Cent	9 Per Cent
Permeability			
Green	2450	2000	2000
Dry	Unobtainable		
Compression			
Green	15.3	16.1	7.6
Dry	Beyond the scale or plus 93.5		
Shear			
Green	1.0	1.3	0.6
Dry	5.6	6.3	8.3
Tensile			
Dry	nil	0.3	0.3

Sintering point 1100 degrees C.

It will be noticed that the green and dry compression are very good. The green compression is higher than that found in the average American naturally bonded sand. The green shear is fair but the dry shear is lower than that which is generally recorded in the naturally bonded sands. The tensile strength is, of course, very low even in the dry state. It does not seem feasible to add a higher percentage of raw clay to the mixture to increase the tensile strength as the working qualities would be impaired by the material becoming very sticky. One of the many cereal binders might be used in place of the extra raw clay. The only bad feature of this is that the sintering point would be lowered appreciably.

A perusal of Captain Shane's notes shows that a number of casting producers use the new Chamotte as a facing sand while the worked over Chamotte is used as the backing sand. Sometimes fine silica sand is mixed with the Chamotte facing, as at Etablissements Cail, Denain, France, in order to produce castings with smooth faces. At Jacob Holtzer, St. Etiennes, a mixture of two parts Chamotte and one part silica sand with about 2 per cent coal tar added for a binder is used as a facing sand. At Gulehoffnungshuette, Duesseldorf, virgin Chamotte is used as a facing of about one inch thick, the backing sand then consists of reclaimed Cha-

motte, or naturally bonded sands. This practice of using poorer grades of sand as a backing sand with the Chamotte facing appears to be quite common as this procedure is followed at the Bergische Stahl Industrie at Remscheid, Germany, Krupp at Essen, Vereinigten Stahlwerke at Bochum, and at the Skoda Works at Pilsen, Czechoslovakia.

Why a highly permeable facing sand such as Chamotte should face a much less permeable natural sand was not explained by these manufacturers but since the practice is so universal it must have some merits.

In practically all large or important castings Chamotte is used, if not as the entire molding sand then as a facing sand.

In explaining the benefits of Chamotte the representatives of Schneider and Company, France, pointed out that the high roasting tempertaures employed drives off all the volatile matter and the small amount of volatile matter that is reintroduced by the addition of the raw clay is insufficient, with proper venting to cause blow holes.

In some cases a mold wash is not used; this applies especially when fine silica sand has been introduced into the facing so that the sand will not be so open. It is claimed that an excellent surface is obtained under such conditions. Several manufacturers make a wash that consists of finely pulverized Chamotte which they paint on the mold surface. In many cases graphite is added to the finely pulverized Chamotte to improve the surface. Other manufacturers prefer a black lead wash for both molds and cores.

Cores are also made of Chamotte, especially large cores that consist of a facing of chamotte and a backing of coke, or cinders.

A very interesting test was made on Chamotte in order to study its rate of heat transference. A 6-inch diameter sphere with a 3-inch central downgate was molded in Chamotte. About 120 pounds of Chamotte were used to make the mold. Thermocouples were molded into the mold at ⅛, ½, 1, 2, and 3 inches from the mold metal interface. A finely pulverized Chamotte wash was painted on the mold surfaces and the mold dried. As soon as the mold was poured temperature readings were taken so that the 5 couples were read every minute. The results are shown in Figure 1. It is interesting to note that the temperature as recorded by the couple at the ⅛-inch position coincides with the ½-inch

position thermocouple after 45 minutes. This shows the rapidity with which heat is being carried away from the casting surface. Another interesting feature is that sand one inch away from the casting never attained a temperature much above 1100 degrees F. and it took over a half an hour to reach this point.

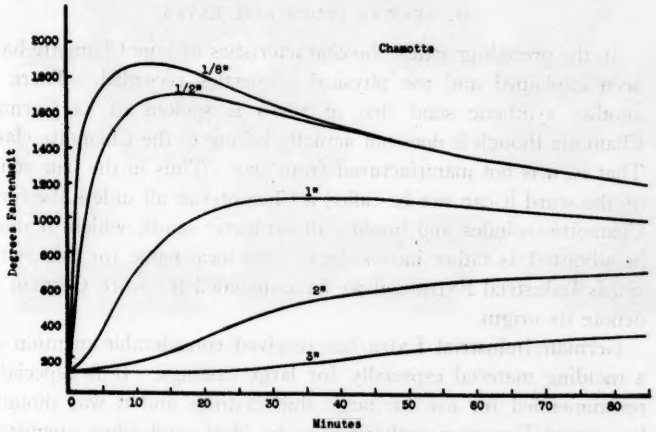


FIGURE 1.—CURVES INDICATING THE TEMPERATURE GRADIENT IN A CHAMOTTE MOLD.

A curve of this type is very interesting to foundrymen for many have never realized the insulating characteristics of sand and the heat distribution through sand.

Chamotte has a rather high rate of heat transference as will be seen when it will be compared with other curves that are to appear in this article. This high thermal conductivity is due to two factors: first, Chamotte as a calcined clay has in itself a higher thermal conductivity than that possessed by silica grains; and second, the large interstices offer a means of rapid heat transference by radiation. The latter is important only at the higher temperatures and this explains the fact that the rate of heat transference is apparently greater near the mold metal interface than it is at distances of two to three inches from this point.

The large grains which are, of course, responsible for the large interstices can be compared to the grains of other sands in Figures 2, 3, 4 and 5.

It will be noted that the German Industrial Extra contains some large angular grains which are, in some cases, larger than those of the Chamotte. There are, however, so many smaller grains present that this sand does not have these large interstices in the rammed condition.

II. GERMAN INDUSTRIAL EXTRA.

In the preceding article the characteristics of true Chamotte have been explained and the physical properties recorded. There is another synthetic sand that at times is spoken of as German Chamotte though it does not actually belong to the Chamotte class. That is, it is not manufactured from clay. Thus in the true sense of the word it can not be called a Chamotte at all unless the term Chamotte includes and implies all synthetic sands, which, it must be admitted, is rather inconsistent. The local name for this material is Industrial Extra and we have included the word German to denote its origin.

German Industrial Extra has received considerable mention as a molding material especially for large castings. It is especially recommended for use for large ship castings and it was thought by several European authorities to be ideal sand when quantities of sand are necessary. It was recommended to the Navy Department as molding material for hull castings. The sand properties as given in this article were obtained by tests made on a trial lot of Industrial Extra that the Navy obtained for examination.

German Industrial Extra is composed mostly of quartz and chalcedony grains. Some of the smaller quartz grains appear to be fairly well rounded, the larger quartz grains and the chalcedony grains are very angular. Pieces of carbon can be seen occasionally.

The chemical analysis is given in Table IV.

TABLE IV.

Total volatile matter, per cent	5.61
SiO_2	72.50
Al_2O_3	19.75
Fe_2O_3	1.59
CaO	1.11
MgO	0.00

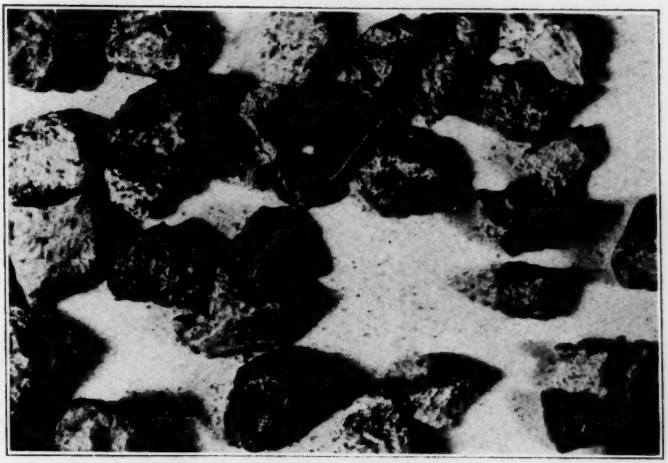


FIGURE 2.—CHAMOTTE GRAINS 10 DIAMETERS.

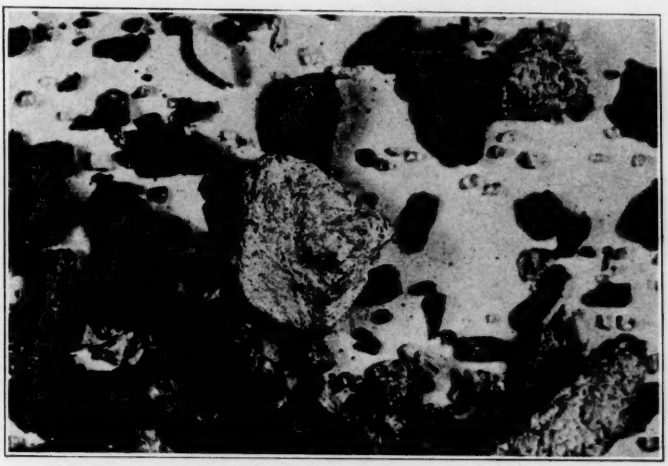


FIGURE 3.—INDUSTRIAL EXTRA GRAINS 10 DIAMETERS.

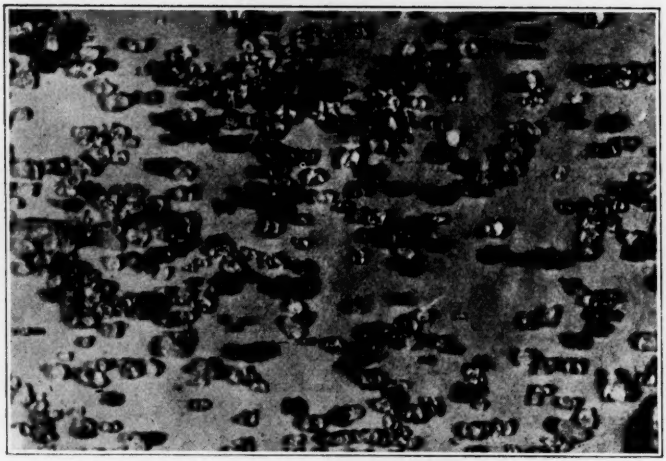


FIGURE 4.—WASHED SILICA GRAINS 10 DIAMETERS.

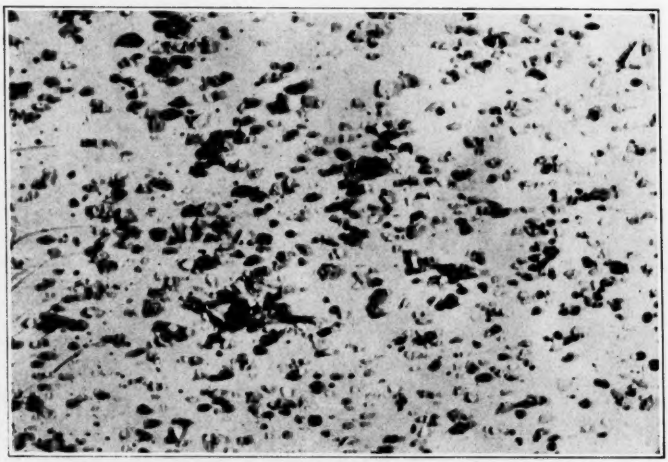


FIGURE 5.—EDELSCHLICHTE GRAINS 10 DIAMETERS.

The method of manufacture is to crush up quartz and chalcedony to the required size and add to it clay and a little pulverized carbon. This is mixed thoroughly and sold ready for the addition of the water.

The screen analysis shows a product that is not at all uniform. In fact there does not appear to be any attempt made to grade the sand. Synthetic sands, as a rule, are graded so that the bulk of the grains falls on one or possibly two screens and even the naturally bonded sands of this country usually show more graded characteristics than the German material.

It was thought advisable to include a good, naturally bonded American sand in order that a more complete comparison of the physical properties of the German Industrial Extra and Chamotte might be obtained. As most American foundrymen are familiar with the Downer naturally bonded sands one of these will be used for comparison.

The particular Downer sand selected is a semi-bonded sand. That is, it can be used in the condition received for many operations but its properties can be improved by the addition of small amounts of cereal binders. At the Naval Research Laboratory a small percentage of clay is usually added also.

The screen analyses of these two sands are listed in Table V.

TABLE V.

Sieve No.	Industrial Extra Per Cent	Downer Per Cent
Retained on 6	5.32	0
12	11.24	.10
20	8.24	.71
30	3.22	1.89
40	3.02	6.33
50	3.72	15.54
70	15.20	32.41
100	11.76	32.23
140	2.36	4.66
200	2.12	.65
270	1.40	.40
Pan	6.04	.45
Bond	26.02	4.63
Total	97.66	100.00

The 26.02 per cent bond listed for the Industrial Extra included clay bond and the carbon that could be floated over.

From the above table it can readily be seen that the naturally bonded sand is the better graded sand.

In preparing Industrial Extra for molding care must be taken that the correct moisture content is maintained. If the sand becomes too moist it will pack too solidly and, when dry, will be too close to allow gases to escape.

The properties of Industrial Extra were obtained with varying water contents and are reported in Table VI.

TABLE VI.

	Water Content		
	4 Per Cent	5.5 Per Cent	7.5 Per Cent
Permeability			
Green	36	48	97
Dry	42	61	130
Compression			
Green	16.9	18.8	15.4
Dry	Beyond scale or +93.5		
Shear			
Green	1.4	1.5	1.3
Dry	7.5	9.9	21.3
Tensile			
Dry	nil	.18	.30

Sintering point 1000 degrees C.

From the above it is noticed that the 7.5 per cent water content gives the best results. Testing with higher percentages of water was not resorted to as the sand "balled-up" badly with the 7.5 per cent water content and was rather difficult to mold. A 7.0 per cent water content appears to be the best to use. In comparing Industrial Extra with Chamotte two outstanding features are noticed. In the first place the green and dry permeability are considerably lower, and secondly, the Industrial Extra has a higher dry shear strength. It is remarkably interesting that, as the water increases the permeability increases. In most sands the reverse

case is found to hold. This is due to the balling action which, though not perceptibly noticeable until about 7 per cent water is added, is present even with smaller additions of water. When the sand is screened small balls, roughly the size of the mesh used, are formed.

The ramming action exerted by three blows of the standard rammer is not sufficient to force these agglomerates together and as a result large air spaces are present between them and an unusually high permeability reading is obtained. If, however, harder ramming is resorted to, such as would probably be used in a mold to insure a good surface, these interstices are closed and the material is almost impermeable. For this reason, and the fact that with high water content the material becomes very sticky and almost impossible to mold, the water content must be closely controlled.

Using the Downer sand as a medium for comparison, the physical properties are reported in Table VII.

TABLE VII.

	Downer
Permeability	
Green	70
Dry	87
Compression	
Green	3.1
Dry	Beyond scale or plus 93.5
Shear	
Green	0.12
Dry	29.5
Tensile	
Dry	2.87
Sintering point 1100 degrees C.	
Moisture, per cent	5.5

In glancing back over the properties of the Industrial Extra it is noticed that the permeability and green compression is considerably greater than the Downer sand but that the dry shear is somewhat less. The outstanding feature is that the Downer sand has a much higher dry tensile strength.

After the molds have been rammed up with the Industrial Extra a specially prepared mold wash is painted on. This prepared mold wash is known as Edelschlichte. Edelschlichte is mixed with water to the consistency of porridge. Before using, the liquid must be well stirred. It should be painted on the molds soon after the pattern is removed. The molds are then dried at a temperature of from 400 to 500 degrees C. A second coat of mold wash is applied after the molds are dried and while they are still warm so that the moisture will evaporate. On the other hand the molds should not be so hot as to dry the wash too rapidly as it will crack and may break off. If, after applying the mold wash, the molds are so cold that the moisture cannot entirely evaporate they must be redried. If little cracks appear after drying the cracks must be coated with Edelschlichte and then polished.

In most cases it is deemed advisable to apply two coats of Edelschlichte though one coat is enough for thin-walled and light castings.

Edelschlichte consists of the following:

Total volatile matter, per cent	13.84
Carbon	11.00
SiO_2	45.62
Al_2O_3	38.90
Fe_2O_3	1.69
CaO	1.50
MgO	0.00

It will be noted that the total of the above analysis is considerably over 100 per cent. This is due to the fact that "total volatile matter" and "carbon" are in a manner duplicate analyses. That is, the "total volatile matter" minus the "carbon" is equal to the volatile inorganic and organic material plus the water not driven off at 105 degrees C.

From this analysis it is seen that the wash is made up of sand, as a base, with a high percentage of clay added along with a fair percentage of carbon to give the casting a smooth surface.

The Edelschlichte is very fine as is shown by the grain distribution given in Table VIII and shown in Figure 5.

TABLE VIII.

Retained on 20	0.0
30	0.06
40	0.2
50	1.02
70	4.46
100	10.6
140	9.36
200	10.08
270	6.18
Pan	23.00
Bond	35.0
Total	99.98

Practically 95 per cent is minus 100-mesh and about 60 per cent is minus 270-mesh.

The permeability of this material is very low, giving 3.8 in the green and 4.9 in the dried state. These figures show that the wash should not be thickly built up on the mold faces.

A mold was made up of Industrial Extra and washed with Edelschlichte to study the rate of heat transference in the mold. The same pattern for a six-inch sphere was used as when studying the heat transference in Chamotte. The thermocouples were molded into the sand at distances ⅛, ½, 1, 2 and 3 inches from the face of the casting. Readings were taken at minute intervals after the sphere was poured with steel. Figure 6 shows the series of curves obtained. In order to have some means of comparison the Downer sand was molded with thermocouples placed in an identical manner as those in the Industrial Extra mold. The Downer mold was given the usual linseed oil-bentonite-silica flour wash. The results of heat transference through the Downer sand are recorded in Figure 7. A study of the graphs will show that Industrial Extra does not conduct heat as rapidly as does the Downer naturally bonded sand. This is particularly noticeable in comparing the results of the couples located at ½ inch from the metal. The

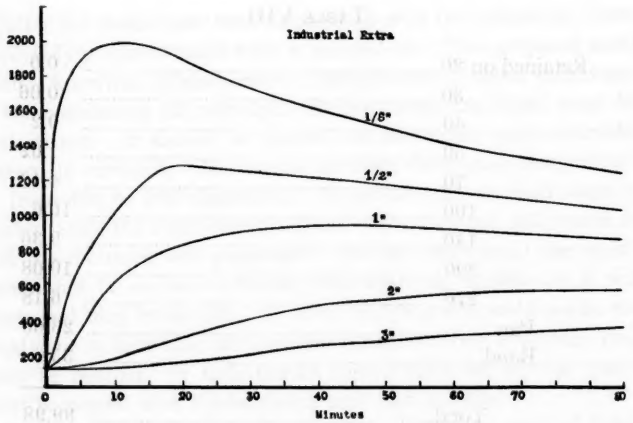


FIGURE 6.—CURVES INDICATING THE TEMPERATURE GRADIENT IN AN INDUSTRIAL EXTRA MOLD.

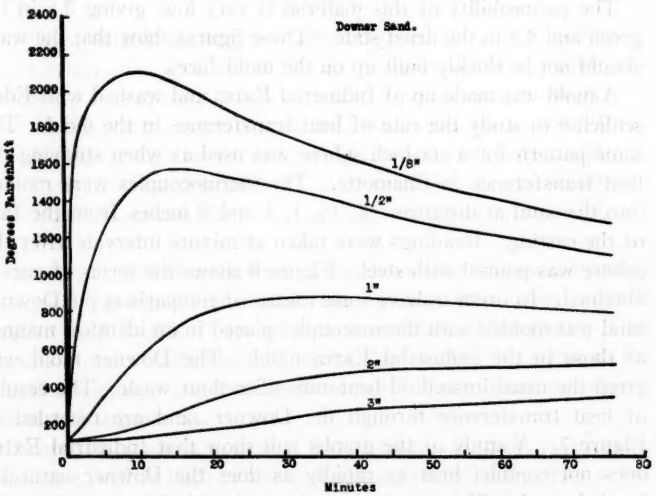


FIGURE 7.—CURVES INDICATING THE TEMPERATURE GRADIENT IN A DOWNER SAND MOLD.

couple in the Industrial Extra reaches only 1280 degrees F. in 20 minutes as a maximum while the corresponding couple in Downer sand records 1580 degrees F. in 15 minutes as a maximum. The 1, 2 and 3-inch readings compare very closely except that the temperatures in the Downer sand, with its higher rate of heat conductivity, show a faster rate of decline.

The importance of the rate of heat transference in sands is not thoroughly known. It has been shown, however, that the slower a casting cools the better physical properties it will have regardless of the following heat treatments. It is also known that casting solidification depends upon the rate with which sand conducts heat, but how important a role it plays in regards to the rate of skin formation, and possibly hot tear formation and other physical metallurgical characteristics of solidifying steel castings is not thoroughly known, for it has been only recently that this phase has been considered at all.

A sand that has a high heat transference should not burn onto the casting as readily as the heat is conducted more rapidly away from the mold metal interface. This is portrayed by the Chamotte. The ½-inch couple reads high temperatures and the ⅛-inch couple shows low temperatures, thus showing that the sand next to the casting was not under a prolonged high heat.

This comparatively high thermal conductivity in Chamotte may explain why European foundries use only a facing of Chamotte and fill the remainder of the mold with a natural sand thereby reducing the rate of heat transference. Economical reasons probably have some bearing on this custom also as the natural sands, being obtained locally, are probably cheaper than Chamotte.

Considered from the standpoint of permeability, a mold of this character (Chamotte facing and natural backing) has serious disadvantages. The highly permeable facing with its large interstices contains a considerable amount of enclosed air which, upon being heated rapidly when the casting is poured, expands enormously, Therefore, unless the less permeable backing sand is carefully vented there is danger of obtaining a porous casting due to the enclosed air escaping through the mold cavity rather than through the mold itself.

III. CEMENT BONDED SANDS.

A more recent addition to the list of European molding materials is the cement-bonded sand. This molding material is used exclusively in the plant at Ugines in the French Alps.

At this particular plant there are no drying ovens, no flasks and very few patterns. Most of the molds are prepared in core boxes or by the use of strickles and templates. Most of the work, except for complicated molds, is done by helpers. As the work at this plant is standardized to a very high degree each operation is indicated on production cards and separate crews of men mold and assemble the molds after they are air dried.

The sand used is a mixture of silica sand and a good grade of cement. The mixtures used at this particular plant are of three types, (1) new sand, (2) part new and part old sand and (3) all old sand. The compositions of these mixtures are listed below:

(1) New sand—
78–76 per cent silica sand.
12–14 per cent cement.
10 per cent water.

(2) Part new and part old sand—
Mixture of 60 per cent new and 40 per cent old sand.
78–80 per cent of the above mixture.
12–10 per cent cement.
10 per cent water.

(3) All old sand—
80–82 per cent old sand.
10–8 per cent cement.
10 per cent water.

After molding, either in core boxes or after being "swept up" on the floor, the molds are allowed to air dry. A period of eight hours air drying is sufficient and the molds can then be handled freely and can be trimmed or have nails driven into them without danger of breakage.

No provision is made for venting except in true cores as it is deemed unnecessary. It is not possible to over-ram this material

as when it is rammed too hard the sand flows out of the mold or corebox. The ramming of the molds is, therefore, very uniform.

In using this sand, new sand is used for very important pieces and as a facing for all steel molds. When used for grey iron a mixture of part new and part old sand is used for the facing. The backing sand is usually composed entirely of old sand. In preparing large cores the conventional coke filling is used.

The advantages claimed for this molding medium are numerous: only one kind of sand is used and as this can be rammed only to a certain degree greater uniformity is obtained; no flasks or drying ovens are required and, therefore, the capital investment is kept at a minimum; and, as helpers can do a large portion of the work, production costs are low. There is some difference of opinion regarding the last statement as other foundries claim that, due to the high license fees demanded, the conventional methods are cheaper.

No mold wash is required on molds for steel although a graphite wash is used on iron molds. The castings are readily cleaned and present a good surface appearance.

Care must be exercised in mixing this type of sand as the water content must be closely controlled. All of the physical properties of the sand depend almost entirely upon the amount of water present. The length of time allowed for air drying also affects the physical properties to some extent.

In order to illustrate these two points a series of experiments were conducted using cement bonded sand mixed in the following proportions by weight: 90 parts silica sand and 10 parts Portland cement. The above mixture was mulled for four minutes after adding water in varying amounts, analyzing at 7.2 per cent, 9.9 per cent and 11.6 per cent. The test specimens must be prepared soon after mixing for, as this molding medium is really an underhydrated concrete, the mixture will harden if allowed to "temper" for any considerable period of time.

A large number of specimens were prepared and samples tested at 24, 48, 72, 120 and 168 hours after preparation. These results are tabulated in Table IX and shown graphically in Figures 8, 9 and 10.

TABLE IX.

A.F.A.	7.2 per cent water						9.9 per cent water						11.6 per cent water					
	Hours air dried						Hours air dried						Hours air dried					
Test	0	24	48	72	120	168	0	24	48	72	120	168	0	24	48	72	120	168
Permeability	87	97	102	102	100	100	52	56	58.3	61	57.9	63.3	28.6	34.6	36.6	34	37.3	41.3
Compression	1.4	Beyond scale of instrument		+	18.8		1.5	+18.8	Beyond scale			1.3	+18.8	— Beyond scale				
Tensile	Nil	.92	1.53	1.93	1.50	1.46	Nil	1.45	2.23	2.33 +73.5	2.06 +73.5	2.63 +73.5	Nil	1.3	2.0	2.1	1.76	1.83
Shear	Nil	47.75	62.5	63.2	66.4	61.9	Nil	55.7	65.9	Beyond scale			Nil	34.3	63.1	67.7	70.3	70.9
Sintering point	1150 degrees C.																	

By examining the table, or graphs, it can be seen that this molding medium has the general characteristics of an oil sand. In the green state, immediately after molding, it has a low compressive strength and practically no tensile or shear strengths. After air drying for twenty-four hours, however, all of these strengths have

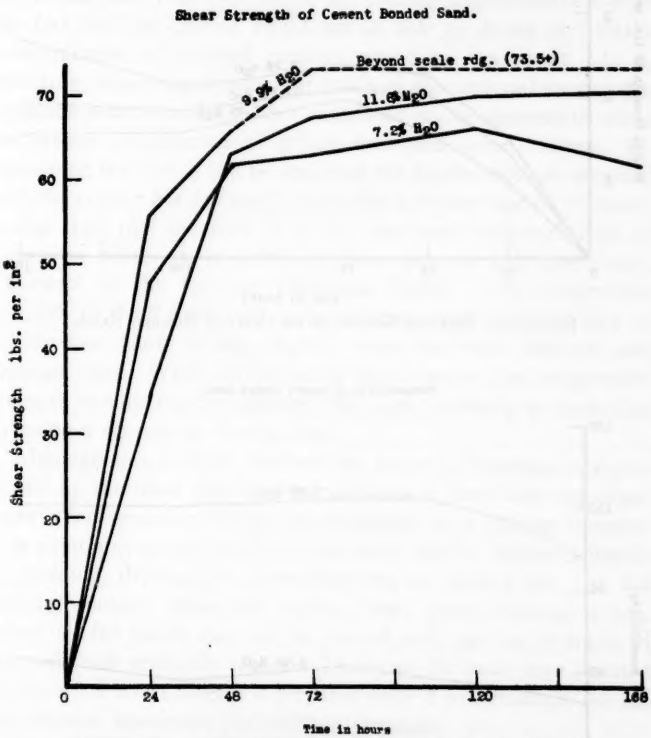


FIGURE 8.—SHEAR STRENGTH OF CEMENT BONDED SAND.

increased enormously but any longer period of drying apparently does not affect any of the physical properties to any great extent.

The importance of controlling the water content can readily be seen by noting its effect upon the permeability which decreases markedly with but a slight increase in the amount of water present. A fully hydrated mixture would, of course, be impermeable.

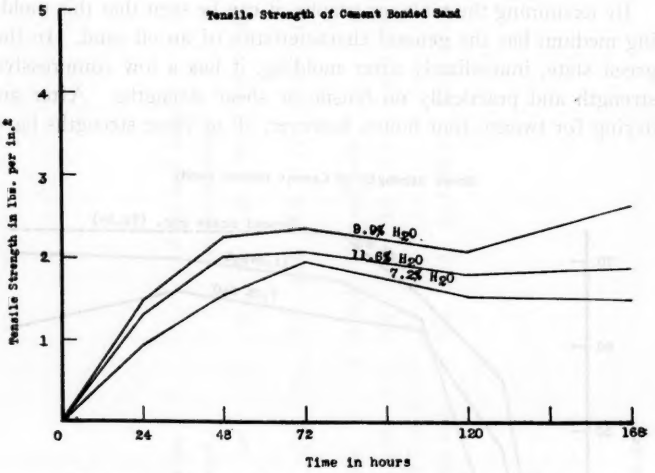


FIGURE 9.—TENSILE STRENGTH OF CEMENT BONDED SAND.

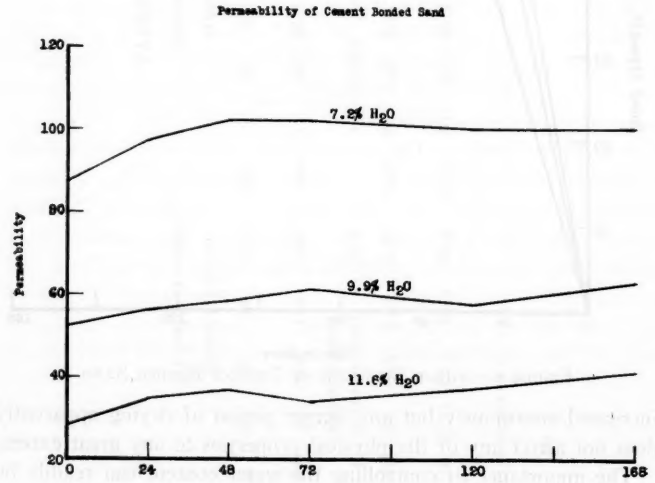


FIGURE 10.—PERMEABILITY OF CEMENT BONDED SAND.

The water content also changes the other physical properties though not to the same extent. The maximum physical properties seem to be obtained with about a 10 per cent water content but this high strength probably is not needed in all cases.

The opinion of many foundrymen in regard to cement bonded molds has been that such molds are entirely impracticable due to the fact that the casting would not be able to shrink and that a predominance of cracked castings would be the result. It is, therefore, surprising to note that molds of this material no stronger or harder than an ordinary dry sand mold can be obtained by using the proper combination of drying time and water content. By examining the data it can be seen that the tensile strength obtained with the cement bonded sand, even after a drying time of 72 hours, is less than that obtained in a dry sand mold although both of these give values far in excess of those obtained with green sand, Chamotte or the German Industrial Extra. The compressive strength of the 7.2 per cent water mixture after a drying time of twenty-four hours is only slightly more than that obtained with Downer sand. With an increase in water content the compressive strength mounts rapidly although this could probably be controlled by using a shorter air drying time.

Although this molding medium has several advantages not possessed by the more conventional methods it does have disadvantages when considered from the standpoint of a jobbing foundry. It is admirably suited to production work when a definite schedule of molding, drying and assembling can be carried out. In the jobbing foundry, especially during times when business is low, where all the molds may not be poured each day the strength of the mold will gradually mount. Then too, the sand must be used within a few hours after it is prepared since it will gradually harden and become unsuitable for molding purposes.

In order that the European sands mentioned above may be compared with both types of sand in use in this country, it might be well to include data obtained from a green sand mixture. These data will apply more to the cement-bonded sand than to either the Chamotte or Industrial Extra as a cement-bonded sand, though possessing physical properties similar to a dried sand, is essentially a green sand.

The mixture selected is one that is actually in use in several steel foundries and consists of the following:

500 parts silica sand.
19 parts bentonite.
1 part Mogul.
1 part Dextrine.
½ part Molasses.

The above mixture was mulled for four minutes with a water content that analyzed at 4 per cent. Test specimens were prepared and tested in the green and, as a matter of curiosity, in the dried state. The results obtained are listed below:

	Green State	Dried State
Permeability	173	219
Compression strength	3.5	Beyond scale +93.5
Shear strength	Nil	40.7 pounds per square inch
Tensile strength	Nil	.8 pounds per square inch

The comparison of the data obtained in the cases of the cement-bonded sand and the above green sand shows the reaction of the two types of bonding materials as the silica sand used in each as a base was from the same bin. The grain distribution of this sand, and of the sands mentioned previously, is shown diagrammatically in Figure 11.

The permeability and the compression strength of the green sand are considerably better than those obtained with the cement binder. The shear and tensile strength are nil in each case. After the cement-bonded sand has air dried for twenty-four hours, however, its strengths are even better than those obtained from the green sand by baking.

In Figures 1, 6 and 7, are curves portraying the rate of heat transference in sands. The cement-bonded sand and the green sand were also studied in an identical manner, Figures 12 and 13. These molds were all poured at practically the same temperature, there being merely the short pouring interval between the molds that is accompanied by a slight temperature drop. Thus the amount of heat to be released through the sand was practically

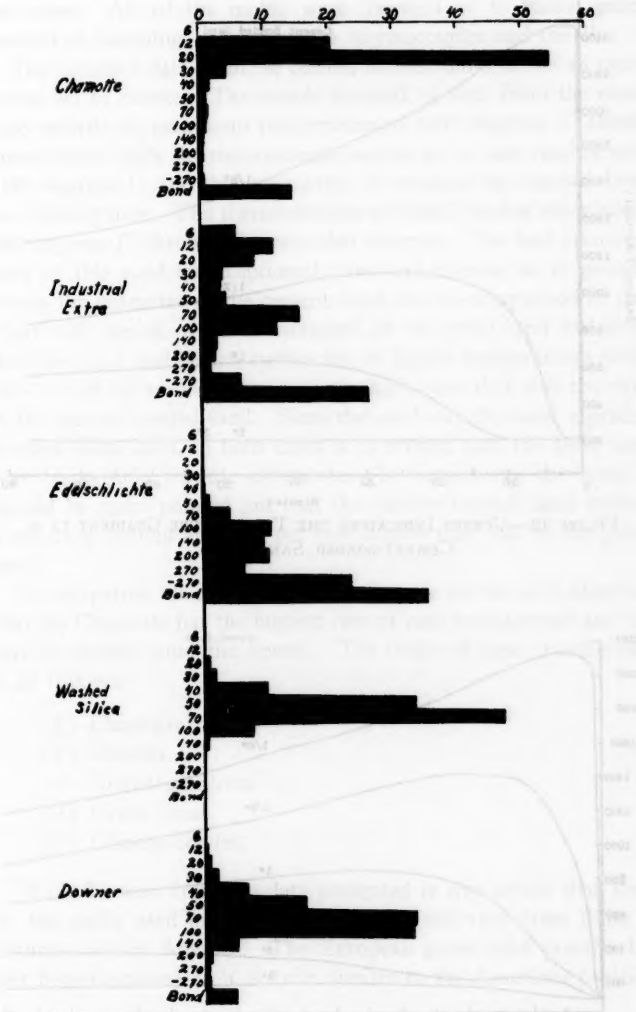


FIGURE 11.—GRAIN DISTRIBUTION OF SOME FOREIGN AND DOMESTIC MOLDING SANDS.

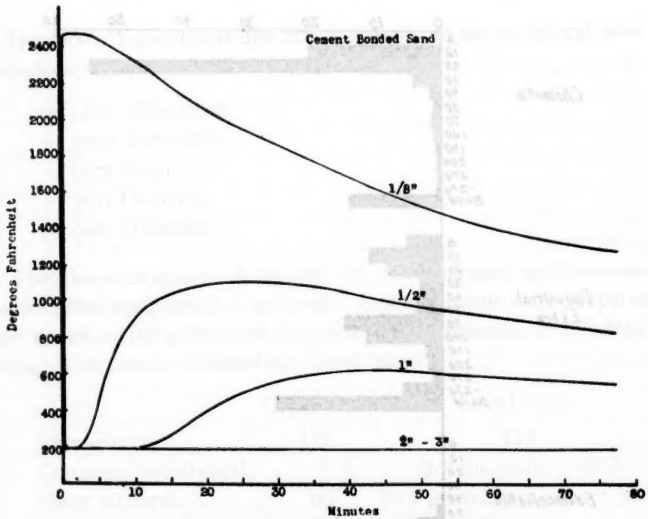


FIGURE 12.—CURVES INDICATING THE TEMPERATURE GRADIENT IN A CEMENT-BONDED SAND MOLD.

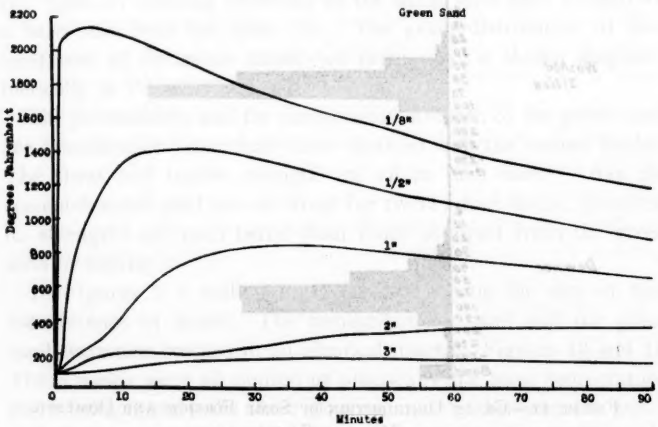


FIGURE 13.—CURVES INDICATING THE TEMPERATURE GRADIENT OF A GREEN SAND MOLD.

the same. All of the molds were identical as to flasks, gates, method of ramming, spacing of the thermocouples and the like.

The recorded data from the cement-bonded mold shows an interesting set of curves. The couple situated ⅛ inch from the metal face records its maximum temperature of 2470 degrees F. almost immediately while the thermocouple located at ½ inch reaches only 1120 degrees F. and that only after 25 minutes has elapsed from the pouring time. The thermocouples at 2 and 3 inches show about 200 degrees F. through the recorded interval. The heat transference of this sand is exceptionally low and it must be in general due to the character of the cement bond since a comparison of this chart with the set of curves obtained on the green sand will show that the ½, 1 and 2-inch curves are of higher temperatures while the ⅛-inch curve does not reach the high peak that was recorded in the cement-bonded sand. Since the sand was the same, a graded washed silica sand, in both cases it is evident that the bond used was responsible for the difference. In considering the bond it should be again pointed out that the cement bonded sand carried a moisture content almost 4 per cent higher than that of the green sand.

In comparing all of the heat transference curves it is observed that the Chamotte has the highest rate of heat transference and the cement-bonded sand the lowest. The order of heat transference is as follows:

(1) Chamotte.
(2) Downer.
(3) Industrial Extra.
(4) Green Sand.
(5) Cement-bonded.

It can be seen from the data presented in this article that some of the sands used in Europe are entirely different from those in common use in America. The European green sand practice has not been discussed as it is quite similar to the American practice.

A SHORT HISTORY OF THE NAVAL USE OF FUEL OIL.

PART II.*

BY LIEUTENANT JAMES E. HAMILTON, U. S. N., MEMBER.

IV. 1910 TO 1916—THE RISE OF OIL.

This period opens with the mechanical problems of handling and burning fuel oil satisfactorily settled. Of course, these problems never have been nor ever can be considered to be finally and completely solved but by 1911 the art had advanced to the point where it was possible to relegate it to the background and to permit other phases of the fuel oil question to occupy the center of the stage.

During this fourth period, liquid fuel made its greatest gains in that all phases of the question were thoroughly studied and fairly definite policies were enunciated for each one. The period culminated with the report of the Navy Fuel Oil Board which would have led to a new fuel oil era had the war not intervened and prevented the realization of the recommendations of the Board.

From 1910 it is necessary to subdivide the general question and to consider each division separately. This need has been previously mentioned. In addition to the subjects listed before a separate section is devoted to the work and report of the Fuel Oil Board because of the general scope of this Board's work.

1. UTILIZATION.

The growing use of fuel oil and the crying need for experimentation to determine the best methods of burning and to test and study designs of fuel oil equipment led the Bureau of Steam Engineering to establish a laboratory for the specific purpose. It had been originally contemplated that the Experiment Station at Annapolis would absorb the fuel oil work. It was now apparent that the magnitude of the work which would be required coupled

* This is the second article of a series; others of which will appear in subsequent issues.

with the volume of that which had already been assigned to Annapolis clearly indicated the need for a separate laboratory.

There was no specific appropriation for the purpose and since the Bureau always had several places to put each dollar which it had, economy was essential. Space was available at the Philadelphia Navy Yard which was also admirably located, central to equipment manufacturers and oil refineries. Three boilers and enough other equipment already owned by the Navy were assembled at Philadelphia, and the Fuel Oil Test Plant opened there for work in the latter part of 1911. The plant was built by the Navy Yard under the direction of the Engineer Officer, Captain B. C. Bryan, U. S. N. Lieutenant Commander (now Captain) J. J. Hyland, U. S. N., attached to the yard engineering department at the time, was placed in charge of the laboratory.

Establishment of the Fuel Oil Test Plant accomplished one very definite result. The former policy had been that when any new fuel oil equipment was developed and offered for naval use, a board was appointed to investigate and report. Now, except for cases where military necessity required the formality of a board, these matters were all turned over to the test plant.

The change from formal investigation to the inconspicuous routine of a laboratory is partially responsible for the fact that fuel oil burning lost its spectacularity. Development since 1911 had been continous. During the pre-war period tests of burners and boilers were conducted but probably the most important function of the Fuel Oil Test Plant in its youth was the training of men. The firemen and watertenders who commissioned and operated the early oil burning ships received their training in the Oil Burning School which was a part of the test plant and under the same head.

In 1914, the Vera Cruz incident created a demand for officers at sea. Hyland, among others, was ordered to sea and, due to lack of personnel, the plant was closed for nearly ten months until Lieutenant (junior grade) (now Commander) A. M. Penn, U. S. N., reported and reopened the plant in February, 1915. A large part of Lieutenant Penn's tour of duty was devoted to studies in connection with the use of Mexican fuel oil. This subject is discussed in the next section.

The Fuel Oil Test Plant was begun as a child of the Bureau of Steam Engineering and has always retained that status. It has always been the technical adviser to the Bureau on questions of fuel oil characteristics and the design of fuel oil equipment for naval vessels.

2. QUALITY.

The quality of naval fuel oil has been more affected by the source than by any other factor. A history of the fuel oil specifications was published in the JOURNAL OF THE AMERICAN SOCIETY OF NAVAL ENGINEERS for May, 1933. During the pre-war period the greatest influence on quality was brought to bear by the apparent shift of the major source from Oklahoma, Texas, and Kansas to California and Mexico.

During the earlier fuel oil years, the Navy's fuel oil came from the Gulf Coast of Texas and little difficulty was experienced in obtaining satisfactory fuel oil in the relatively small quantities required. In 1912 the general adoption of oil was in sight and it appeared that in the future the Navy would have to depend on California and Mexican fields for the majority of the fuel oil supply on the West and East Coasts, respectively.

There were three particular characteristics of the fuel oils from these two regions which differed from those of the fuels in general use by the Navy. The original crude (true of only a portion of the California production) contained high percentages of sulphur and asphalt, its gravity was high and its fluidity low. As a result of these characteristics, the fuel oil residues of these crudes were also of low quality in these respects. In addition, the gasoline content of some of the crude was so low that much of it was marketed directly as fuel oil without any reduction. This fuel oil had a very low flash point.

Not only would the Navy's refusal to accept California and Mexican fuel oils result in an increased fuel bill but it might entirely upset the policy of adopting oil for universal naval use by making it impossible to obtain a sufficient supply. Three investigations were undertaken to study the question of the use of Mexican and California fuel oils.

The first investigation was assigned to the Torpedo Flotilla, Atlantic Fleet, Captain (later Admiral) E. W. Eberle, U. S. N., Commanding. The Bureau arranged for a supply of California fuel oil at Colon, Panama, and directed that the oil-burning destroyers of the Torpedo Flotilla obtain this oil and determine its value comparative to Gulf fuel oil on four runs, namely: smokeless combustion, economy, full power, and in port. The destroyers fueled in January, 1913, and ran the tests en route from Colon to Guantanamo Bay, Cuba. The vessels which participated were: *Fanning, Paulding, Warrington, McCall, Roe, Jouett, Terry, Sterett, Henley, Drayton, Jenkins, Ammen, Trippe, Jarvis, Monaghan, Burrows* and *Patterson.*

Of the seventeen boats only three, the *Fanning, Paulding,* and *Jouett,* submitted full reports covering all four conditions. The following table shows the number of destroyers which made full reports on each run and clearly shows the necessity of using a large number of service tests in order that sufficient data be obtained on any investigation:

Run	Number Which Made the Run
Smokeless combustion	12
Economy	15
Full power	4
In port	9

The objections which were raised to the California oil by the various destroyers were numerous. Most of the destroyers reported that it was impossible to run smokeless and that clogging of strainers and burners and fouling of firesides of boilers was excessive. Only one vessel, the *Jouett,* reported that the California oil could be satisfactorily used.

Apparently the California fuel oil was condemned for naval use. However, the reports from the flotilla were sent to the Fuel Oil Test Plant for its consideration. It was reported by most of the destroyers that the oil to the burners had been heated to a point 20 degrees F. below the flash point as limited by existing instructions. As the flash point of the oil used was about 148 degrees F., the heating permitted was insufficient and the result was heavy

smoke and boiler deposits. This point was brought out by the Fuel Oil Test Plant, which recommended that in purchasing oils of the California type, the flash point be limited to not less than 175 degrees F., which would permit satisfactory burning under the then current instructions.

The data collected by the flotilla, together with the oil burning experience of the Fuel Oil Test Plant, led to a very simple solution to the problem of burning California oils. This solution has been proven by many years to have been basic and correct.

The second investigation of this period was that of what came to be known as the Flash Point Board. The rising price of oil had in 1913 led to a lowering of the specification flash point from 200 degrees F. to 150 degrees F. for the fiscal year 1914. On 28 March, 1913, the Secretary of the Navy convened a board of which Lieutenant Commander David F. Boyd, U. S. N., attached to the Bureau of Steam Engineering, was senior member; Lieutenant Commander J. J. Hyland, U. S. N., officer in charge of the Fuel Oil Test Plant, and Doctor David T. Day of the U. S. Geological Survey were members; and Naval Constructor (now Chief of the Bureau of Construction and Repair) Emory S. Land, U. S. N., was member and recorder.

The reason for convening the board as given in the precept was "* * * for the purpose of ascertaining whether a minimum flash point of 150 degrees F. is safe for fuel oils stored and used on board naval vessels, and further, in case this temperature is found to be undesirable, to recommend a proper limit."

In its investigations the flash point board covered the following points:

a. Actual temperatures encountered on board naval vessels.

b. Nature and volume of hydrocarbon gases released on board ship from fuel oil.

c. Temperatures to which oils had to be heated for pumping.

d. Temperatures to which oils had to be heated for smokeless combustion.

e. Actual value of "flash point" as a determinant of safety or danger at elevated temperatures.

Then, to make the report complete, an investigation as to the effect of sulphur in fuel oil was made and, in addition to a report

that the specified flash point of 150 degrees F. was satisfactory, the board submitted a recommendation for a complete specification. This specification was sufficiently broad to include a large percentage of the fuel oils of both Mexico and California.

The third investigation was a service test of Mexican fuel oil. In 1914, the U. S. S. *Jarvis* made comparative runs of 18-degree Beaume Mexican fuel oil and 28-degree Beaume Texas oil and reported that the former could be very satisfactorily used. This test stood practically alone for two years. In August, 1916, the Bureau of Steam Engineering informed the Commander-in-Chief, Atlantic Fleet, that a supply of Mexican fuel oil had been delivered to the fuel depot at Melville, R. I., and requested a report on the use of this fuel from each vessel to which it was supplied.

Reports were submitted from various vessels during the next three months and the results were digested by the Bureau and by the Fuel Oil Test Plant. The difficulties which were encountered were very similar to those previously reported on the California oils with the addition that the oil was very hard to ignite when starting out cold and that its viscosity was so high that pumping difficulties were experienced.

Under date of 9 December, 1916, a very comprehensive digest of the service test reports was submitted by the Fuel Oil Test Plant. This report ascribed many of the difficulties to poor operation but recommended certain equipment modifications if ships were to be supplied with heavy Mexican or other fuel oils. At the time of this report, the effect of viscosity on pumping and burning fuel oils was fully recognized. Previously, the difficulties with the "heavy" oils had been ascribed to high specific gravity when in reality it was high viscosity. The Mexican oil was more viscous than that from California and hence required higher temperatures both for pumping and atomizing.

On 13 December, 1916, the Bureau of Steam Engineering informed the Chief of Naval Operations that the tests had been made and that they indicated the necessity for certain modifications of fuel oil equipment. The Bureau requested that a destroyer be detailed to work in conjunction with the Fuel Oil Test Plant in developing the necessary modifications.

As this request was modified by later developments described under Section 7—" The Navy Fuel Oil Board," discussion of the action which was taken will be deferred to that section.

3. APPLICATION.

The United States entered this period with a definite policy concerning application. All new destroyers and submarines were to use fuel oil exclusively. Battleships were to carry oil as an auxiliary to coal, each capital ship carrying about 400 tons of oil. This latter policy was a compromise. Oil had been proven to be the ideal fuel for naval and marine purposes and would, in all probability, have been the sole fuel at this time except for uncertainty as to the problems of supply and distribution. Destroyers would normally operate from domestic ports to which oil supply could be assured and from which the distribution of the fuel could be effected. The conservative element in the Navy could not see the way clear to building ships whose normal and proper function might be interfered with because of the lack of a worldwide chain of oil-fueling stations.

From September, 1910, when the first oil-burning destroyer was commissioned, reports of the superiority of the liquid fuel were received with increasing frequency. The reception of oil on the battleships was also enthusiastic. In these ships it was used alone in preference to coal on all possible occasions. Immediately after trials were started on the destroyers, the smoke question was definitely settled favorably. The destroyer engineers and shipbuilders together experimented on this problem and discovered that changes in the registers to give increased air velocity with the same volume into the furnace, permitted smokeless combustion even at high rates. Control of smoke gave the naval tactician a new tool in the smoke screen. Engineering performances of exclusively oil- and exclusively coal-burning destroyers showed the comparative superiority of the oil-burning installations in all respects except cost of the fuel.

Under the stimulus of the remarkable strategic and tactical advantages offered by liquid fuel, and the favorable operation reports received from all sources; and probably with a prayer that all of the possible logistic difficulties would be overcome if they actually

arose, the Navy Department in the latter part of 1911 drew up the plans and specifications for the *Oklahoma* and *Nevada*, designed for the exclusive use of fuel oil. The results of the plans was a delight to the naval officer's eye. The new battleships were so much superior to their predecessors that it is very easy to believe that any misgivings were overcome. However, there can be little doubt that some uncertainty existed as to the wisdom of building ships which for years would form part of the battle line but which could not be converted to coal-burning without complete rebuilding.

The *Oklahoma* and *Nevada* had the lightest machinery installation by more than one hundred tons of all of the 21-knot dreadnaughts. Their firerooms were grouped into a space but half the length of that needed in coal-burning battleships. Some 60 fireroom billets were eliminated. Years before, Commander Edwards had said in his War College lectures that naval engineering could never reach its full efficiency until other branches would surrender and allow more space and weight for the engineering plant. As ships grew, this increased space and weight had been grudgingly given. Now with the single change from coal to oil the engineers not only increased their efficiency and the military availability and capability of the battleship, but they returned to the constructors one-fourth of the weight and one-fifth of the space and released one-third of the men which they had been accustomed to require.

The adoption of oil exclusively for these ships was a tentative move and not a definite change of policy. However, the continued contemplation of what could be done by the elimination of coal and the continued favorable reports from the fleet made it very difficult to consider having to continue to burn coal. In 1912 it became necessary to lay the question, "Can enough oil be assured for a sufficient length of time to justify the Navy's adoption of fuel oil to the exclusion of coal?" An affirmative answer would remove the only bar. The question was put by the Secretary of the Navy to the Secretary of the Interior. The latter was the government official under whom the U. S. Geological Survey operated and was therefore in the best position to answer the question. His reply, that the supply could be assured for the probable life of any ship which would be constructed during the next ten years, settled all doubts. In his annual report for 1914, the Secretary of the Navy,

Josephus Daniels, announced that in the future all fighting ships built for the United States Navy would burn oil solely. As a matter of fact, the Navy had not designed a coal-burning ship since 1910 when the plans for the *New York* and *Texas* were made.

Thus the question of application was definitely settled in 1911 and formally announced as a policy in 1914. There has been no suggestion of a change back to coal since that date and up to the present time no substitute has appeared. Repeated pronouncements based on thorough study have been to the effect that any need to return to coal would force the United States or any nation so placed into a hopeless position as regards naval supremacy.

In the development of the policy of application of fuel oil for naval purposes, the Bureau of Steam Engineering under the successive leadership of Melville, Rae, Barton, and Cone can be given the major credit. It was these engineers who initiated and executed every major investigation and experiment upon which the decision was based.

Foreign Application:

During this period, development in England had closely paralleled that in the United States. After her temporary defection from oil in the G-class destroyers, England returned to oil for that type of vessel. The five *Queen Elizabeths* were her first all oil-burning capital ships. These were actually designed and started after the *Oklahoma* and *Nevada* were, but they were completed first and hence England gained the right to claim the first oil-burning battleship as she had previously done with the first single main battery battleship when her *Dreadnaught* beat the *Michigan* to completion.

For heavy cruisers of the now defunct armored cruiser type, England had adopted oil as an auxiliary to coal for all of them. The 16 latest light cruisers or scouts were oil-burning while the older ones depended upon coal as the principal fuel with oil as auxiliary.

In the early years of the war a large number of auxiliary vessels were built or taken over for the British Navy. Most of these, including mine layers, sloops, and mine sweepers were coal-burning. It was not desirable to build up too large a demand for fuel oil outside of the fighting fleets.

France was still depending upon coal to a very large extent. Only 11 destroyers had been built for oil alone, the others and torpedo boats being coal-burners. All cruisers and battleships, however, were fitted for using oil as an auxiliary fuel.

Italy was entirely on the fence, that is: all vessels of all types were fitted for both oil and coal but none for oil alone.

Russia was in about the same state as France. Her latest destroyers were oil-burning and the larger vessels carried both fuels.

On the other side, six Austrian destroyers were oil-burners. Practically all other Austrian and German men-of-war were coal-burners, many, however, fitted for some oil in addition.

Japan was still entirely on a coal-burning basis.

4. SOURCE.

The source problem which arose during this pre-war period was destined to become the most spectacular from a general public point of view and probably the most troublesome to the Navy. While the Navy Department hesitated to adopt oil because of the ever-haunting fear of the safety of the future supply, the suggestion was made that the Navy acquire proved oil lands for its own reserve.

The Director of the Geologic Survey, George Otis Smith, had recommended to the Secretary of the Interior in February, 1908, that a reservation of oil lands in the West be made to assure a future supply of fuel oil for the Navy but it was Rear Admiral H. I. Cone, Engineer-in-Chief, who forcefully advocated this move. His efforts were finally crowned with success.

On 27 September, 1909, President Taft withdrew certain oil-bearing public lands from entry as a conservation move. The legality of the withdrawal was questioned by a number of claimants and the President asked Congress to enact a statute which would give him specific authority to withdraw public lands. In the past many withdrawals had been made by executive order without serious challenge. By the Pickett Act of 25 June, 1910, the President was authorized to withdraw public lands temporarily. As this bill neither confirmed or disaffirmed the withdrawal order of September, 1909, the President on 2 July, 1910, confirmed the previous

withdrawal, based now on the Pickett Act. The nine months which elapsed between the two withdrawal orders gave many people an opportunity to make entry on the withdrawn lands and then to base their claims on alleged illegality of the first withdrawal.

On 8 August, 1912, a portion of the above mentioned withdrawn public lands located in the Elk Hills in San Joachin Valley, California, was set aside by executive order to "* * * be held for the exclusive use or benefit of the United States Navy." This area was designated as Naval Petroleum Reserve Number 1. It consisted of 37,764 acres of land favorable as an oil prospect but unproven. On 13 December, 1912, another area designated as Naval Petroleum Reserve Number 2 was set aside. This reserve is contiguous to Reserve Number 1 and located in the Buena Vista Hills. It has a total area of 30,097 acres and at the time of designation was known to be highly productive.

Apparently the Navy Department did not foresee the difficulties which would later beset it because of the petroleum reserves. The Secretary of the Navy, George von L. Meyer, in 1912 mentioned Reserve Number 1 in the following words:

"* * * There is abundant oil in the Government lands of Alaska, California, and Oklahoma, and the department is negotiating for the transfer of some of these lands to the Navy, having secured one area in Southern California by executive order that, according to the estimates of geological experts, will produce 250,000,000 barrels of fuel oil. With the completion of the Panama Canal this oil can be transported to the Atlantic Coast reservoirs at great saving to the Government over the present price of fuel oil. * * *" The quotation indicates that the department was expecting real benefits from the reserves with no great delay. It is also apparent that it was expected that the reserves would be operated and not held indefinitely for future eventualities.

Secretary Meyer's successor, Josephus Daniels, seems to have been of a similar opinion one year later. His first report, that of 1913, contains the following statements:

"I desire to recommend to Congress * * * the passage of legislation that will enable the department to refine its own oil from its own wells. * * * It is advisable from every point of view that the Navy should become a producer and refiner of

oil for its own use. By the time the Panama Canal is opened and the fleet begins frequenting the Pacific the Navy should be producing its own oil from the Navy petroleum reserves in the Elk Hills and Buena Vista fields of California, and its refinery should be in operation. * * *"

Within a year the Navy Department was brought to some realization of the problem which the petroleum reserves were to become. The two areas had been set aside for the Navy by the President but Congress had failed to set up any authorization or appropriation whereby the department could actually take possession of the property and make provision for its protection and development.

As a matter of fact, most of the trouble had its beginning before the reserves were designated to the Navy. After the withdrawal a number of entries were made, many even after the second withdrawal which was backed by the Pickett Act. Based on these illegal entries, considerable pressure was brought to bear on Congress to get legislation to legalize the fraudulent claims. The bills which were prepared for this purpose failed of enactment but they kept the Navy Department on the job to prevent it. The Navy's argument was based on the belief that the conditions of the withdrawal were such that any legal claim would be recognized by the courts and that a demand for legislative protection was an admission of weakness on the part of the claimants.

It was not until February, 1915, that the Supreme Court's decision in the Midwest Oil Co. case definitely validated the withdrawal order of September, 1912.

On 30 April, 1915, 9,321 acres of the public domain in Wyoming was set aside and designated as Naval Petroleum Reserve Number 3. This reserve was completely covered by claims based on the old placer mining laws but no development had been done. The reserve lay directly south of the extremely prolific Salt Creek field. It was expected because of the geologic conditions that the reserve would be valuable.

The Midwest case ruling did not quiet all of the claims to the three reserves so the Navy's title was still clouded. The department, still without funds, was unable to actually take over the reserves. The litigation continued for years and for years efforts were made to get legislative action to deprive the Navy of the reserves.

Congress made available to the Navy for the fiscal year 1916, $10,000 " for the custody and care of naval petroleum reserves," and $50,000 " to enable the Attorney General to represent and protect the interests of the United States in matters and suits affecting withdrawing oil lands and for expenses in connection therewith."

The Navy's first move, as soon as money was available, was to order Lieutenant Commander I. F. Landis, U. S. N., retired, to duty in connection with the naval petroleum reserves in July, 1915. He began investigating the conflicting claims and all matters relating to these lands so that the department would have definite information to lay before Congress.

The 1917 Naval Appropriation Bill dated 29 August, 1916, carried the paragraph:

" Fuel oil: For an investigation of fuel oil and gasoline adapted to naval requirements, including the question of supply and storage and the availability economically and otherwise of such supply as may be afforded by the naval reserves on the public domain, and for the purchase of necessary instruments and appliances for the extension of the naval fuel-oil equipment plant at the Navy Yard, Philadelphia, Pennsylvania, and the temporary employment of civilian fuel-oil experts and assistants, $60,000."

This appropriation is more thoroughly covered in Section 7. Fifteen hundred dollars of it was allotted to Landis to permit him to continue his investigations and orders were issued to him to report on the following points, quoted from a letter of the Secretary of the Navy dated 14 October, 1916.

" 1. Estimates of the total amount of crude oil recoverable from all the land in each reserve.

" 2. Estimates of the amount of crude oil recoverable from lands in undisputed Government ownership in each reserve.

" 3. Estimates of the amount of crude oil recoverable from lands held in private ownership by unassailable titles in each reserve.

" 4. Analysis of the crude oils from each reserve showing the average gasoline content and fuel oil content of the crude oil from each reserve.

" 5. Data from each reserve showing depth of oil measures, cost of drilling, estimated production per well, if practicable; distance

from tidewater; existing pipe line facilities; and exchange value of crude oil in the field for fuel oil at the coast."

Arrangements were made to have a test well drilled in Reserve Number 3 under the supervision of the Bureau of Mines and $25,000 of the $60,000 appropriation was allotted for this purpose.

The previous section has mentioned the growing importance of Mexico and California as sources of fuel oil. Until July, 1914, all fuel oil purchased on annual contract for the fleet was from crude oil produced in Texas, Oklahoma, and Louisiana. Beginning with the fiscal year 1915 deliveries were required on the West coast and California fuel oil was purchased for these deliveries. The following year two out of six contracts for East coast deliveries specified Mexican oil which had previously been excluded. Since that time the source of commercially supplied fuel oil has not been considered as a specification requirement of the contracts. Both Mexico and California were in.

5. SUPPLY.

It is somewhat difficult to differentiate clearly between this section, "Supply," and the following one, "Distribution." There is a very clear line of separation between the two but it is believed that past treatment has failed to make the separation clear. The difficulty lies in the fact that the number and availability of tank steamers and shore storage enter very strongly into both subjects. An attempt will be made to differentiate between the two and to maintain the separation throughout the remainder of this paper.

Supply has primarily to do with the location at which the Navy takes possession of the fuel oil. Circumstances dictate whether the suppliers go to the Navy or the Navy goes to the point of supply. Supply comes under the general head of purchase and is a specific function of the Bureau of Supplies and Accounts.

In 1910 when the first annual contract was entered into for fuel oil, the Navy had but a few oil-burning ships and these were operating on the Atlantic Coast. The Navy had no completed shore storage and but one old tank vessel, the *Arethusa*. It was necessary, therefore, to contract for delivery of fuel oil at the various ports from which the oil-burning vessels were to be operated during

the year. This placed a restriction on the bidding in that only those suppliers who had facilities at these naval ports could compete.

Table I summarizes the contracts for fuel oil during the period from 1 July, 1910, to 30 June, 1917. The table shows the number of contracts which covered all delivery points and the price for four selected points for each fiscal year. The four points selected are Texas Gulf and San Pedro, California, as representing the cost of the oil when purchased at a source center on each coast and New York and Puget Sound as representing the cost at distribution centers on the two coasts. Nineteen fifteen is divided on the West coast because the first West coast contract was entered into with caution and covered supply for only three months. A second set of contracts were necessary to complete the year.

All of the contracts were for indefinite amounts, restricted only by such limitations as the contractor imposed by his bid. This was one feature which made the business unattractive and, in fact, impossible for any but the largest suppliers. A consideration of the fluctuation of prices from year to year explains why the Paymaster General continually recommended that the Navy's shore storage be increased. Large tankage would permit him to buy extra oil during years in which the price was low and to store this oil for use during a subsequent year of elevated prices.

Another repeated recommendation of the Paymaster General was for the construction of a number of tank vessels. This is explained by the wide spread in prices between source and distribution centers as shown by Table I. In many cases this differential was more than ten times as great as the actual cost of carrying the oil in a naval tanker would have been.

The tanker situation was particularly acute during the latter part of this period because of the heavy war demand for oil in Europe and the commercial allocation of most of the tonnage to this extremely lucrative trade. Even at high prices the Navy had difficulty in obtaining tank steamer transportation. The situation was probably saved from becoming embarrassing by excellent planning on the part of the Bureau of Supplies and Accounts even though this planning was not based on an expected shortage of tank steamers. When the bids for 1917 showed that the price would be 21 cents higher than the 64-cent contract price for 1916,

TABLE I.—FUEL OIL CONTRACTS.

Fiscal Year	Number of Delivery Points	Number of Contracts	Price New York*	Tex. Gulf†	San Pedro†	Puget Sound*
1911	16	2	$1.1025	$0.7875	.....	.....
1912	19	1	1.155	.7875	.....	.....
1913	19	1	1.869	1.260	.....	.....
1914	17	1	1.98	1.390	.....	.....
1915—E	19	4	1.27	.78	.....	.....
W_1	7	2	.....	.....	$0.80	$1.00
W_2	7	3	.....	.....	.65	.83
1916—E	19	6	1.11	.64	.....	.....
W	7	5	.....	.....	.60	.76
1917—E	18	2	1.83	.85	.....	.....
W	7	3	.....	.....	.90	1.10

* F.a.s. vessels outside harbor in lots of 1000 to 2500 barrels.
† F.o.b. alongside suppliers' wharfs in lots of over 2500 barrels.

advantage was taken of the lower price to buy about 300,000 barrels of extra oil and fill all available naval storage. This cheap oil in storage saved the situation when the tanker shortage became a supply factor.

Except for the few remarks above on tank storage and vessels as price factors, the treatment of these two subjects properly belongs to the next section.

During the fiscal year 1914 "in compliance with a Senate resolution, representatives of the Navy Department and the Interior Department, aided by the counsel of the Bureau of Mines, investigated the feasibility, desirability, and expense of the Government constructing an oil pipe line from the mid-continent field of Oklahoma to some point on the Gulf and acquiring oil lands and producing, transporting, and refining oil for the purpose of providing at all times an adequate, dependable, and economical supply of fuel for the Navy. This work will be made the subject of a report to the Senate." The quotation is from the Secretary's annual report for 1914.

In the same year the Engineer-in-Chief reported that the pipe line investigation had been made and to that investigation he ascribed a portion of the credit for the reduction in cost of fuel oil which the Navy was enjoying.

Lieutenant Commander (later Captain) David F. Boyd, U. S. N., was appointed as the Navy Department representative to make the pipe line investigation. Under date of November, 1915, a report was prepared and signed by the Secretary of the Navy. The Secretary of the Interior did not agree with the report and did not sign it. It was not submitted to the Senate and apparently the matter was dropped.

The prepared report stated that the project of building a pipe line, storage tanks, and a refinery was entirely feasible, that the project would cost $11,500,000, but that it was not considered desirable for the Government to undertake it. The recommendations are quoted in full:

"We consider it highly desirable, even imperative, that the Government place itself in a position to control a reserve of oil that will enable it to use liquid fuel at a minimum cost over a long period of years. We think it possible to conserve a supply at the present day which would produce this liquid fuel for at least fifty years, and believe that this should be done, by reserving oil bearing areas specifically set aside for the use of the Navy, or by leasing lands subject to the Government's right to claim the production as required, or by retaining the ownership of crude oil produced from leased land to such an extent that the Government should have the right to call for the fuel oil content of such crude at a fairly even price, based on the cost of production.

"In our opinion, if the Navy Department should obtain oil bearing areas, it might prove desirable for the Government to supply pipe-line facilities to whatever terminal is established for controlling its reserve of the raw material, and that it might prove desirable for the Government to conduct the one operation of distilling the light products out of the crude oil, retaining the liquid fuel required for its use and selling the remainder of the crude production to the best bidder at the point at which the distilling operation was carried on. This would reduce the operation to its simplest possible factors and would not result in the Government entering into a business unrelated to its actual naval requirements.

"Should the pipe line and distilling operations be confined to this particular field, we believe that it would be entirely possible

that an efficient corps could be trained by specialists already experienced, to conduct these operations.

"A special corps of oil engineers might be developed and, to meet the peculiar conditions of the oil business, employees might be selected in the usual manner that any Government employees are selected for work in any permanent specialized Government service."

6. DISTRIBUTION.

Providing ships with fuel is a function of operations. Where conditions warrant the arrangement, supply and distribution are combined and the oil first comes into the Navy's possession in the bunker tanks of the vessel which is to burn it. Such an arrangement is, in general, unsatisfactory for military purposes since two separate elements are involved: the naval vessel and the commercial dock, tanker, or barge. Except under war conditions when the entire country and its industries are under quasi-military control, the Navy cannot control the details of fueling.

It is and always has been recognized that the most desirable arrangement would be one which placed in the hands of the fleet, facilities for fueling every combatant naval vessel, whatever it might be from another naval activity. Such an arrangement is divisible into two classes comparable in general to facilities at main bases and at advanced bases.

Fueling facilities at main bases involve shore storage tanks, oiling wharves or docks, and floating equipment, principally barges. Facilities for advanced bases require only tank vessels which themselves obtain their cargoes either from a main naval base or direct from the commercial supplier.

In 1910 the Navy had but one tanker as has been stated, the *Arethusa* with a maximum speed of 10 knots and a cargo capacity of 4500 tons of fuel oil. It had not a single shore storage tank nor a single oil barge.

Fuel Oil Storage:

In 1909, the plan of providing adequate storage facilities was initiated. The Secretary of the Navy was already empowered by law to erect fuel storage where and of such capacity as he deter-

mined to be necessary. Frequently Congress appropriated money for the purpose of enabling the Secretary to comply with this law. Prior to 1909, of course, all such money was used for building coal storage and fueling plants, although the law had been so worded since 1903 that either oil or coal storage could have been built.

In 1914 Congress repealed the authority of the Secretary of the Navy to spend the money for fuel storage at his discretion and took upon itself the function of deciding where the storage should be placed and how much should be provided.

Table II shows the progress made in building up the Navy's oil storage facilities from 1909 through 1916.

Supplies and Accounts found it a decided disadvantage in purchasing oil to have practically no facilities for its transportation. It was necessary almost entirely to purchase the oil delivered into naval tanks or vessels. Starting only with the *Arethusa*, the Navy's tanker fleet was developed slowly. Three colliers were completed in 1911 and four more in 1913 and these were each equipped for carrying a maximum of about 3000 tons of fuel oil in addition to coal. The appropriation act for 1913 included a provision for the construction of " two fuel ships." In the absence of specific designation, the Navy Department elected to build these ships as tankers instead of colliers.

The General Board, headed by the Admiral of the Navy, George Dewey, in a letter to the Secretary in 1914 deplored the shortage of fuel oil tank ships, urged acceleration of the completion of the two fuel ships building and recommended the construction of two additional tankers. No action was obtained on this recommendation until 3 March, 1915, when one oil fuel ship was authorized and appropriated for. On 29 August, 1916, three additional fuel ships were authorized but the necessary appropriation was made for only one. Table III shows the date of commissioning and the cargo capacity of the Navy's oil supply fleet yearly until 31 December, 1916.

Table IV shows the rate of increase in the number of oil-burning ships and the annual consumption of fuel oil by the fleet.

Rear Admiral Sam McGowan, Paymaster-General, as chairman of the Chief of Naval Operations' " Committee on Logistics," can

TABLE II.—OIL STORAGE PLANTS.

Location	1909 tons	1910 tons	1911 tons	1912 tons	1913 tons	1914 tons	1915 tons	1916 tons
Key West	Pro.	Bldg.	5000	5000	5000	5000	5000	5000
Charleston	Pro.	Bldg.	5000	5000	5000	5000	5000	5000
Norfolk	Pro.	Bldg.	5000	5000	5000	5000	5000	26000(b)
Melville(a)	Pro.	Bldg.	5000	5000	5000	5000	12000	12000
Guantanamo	.....	Pro.	Bldg.	Bldg.	30000	30000	30000	30000
Pearl Harbor	.....	.....	Pro.	Bldg.	Bldg.	33000	33000	33000
Boston	.....	.....	.....	.....	Pro.	Bldg.	7000	7000	7000
San Diego	.....	.....	.....	.....	.....	.....	Pro.	7000	7000
Mare Island	.....	.....	.....	.....	.....	.....	Pro.	Pro.	Pro.(c)
Puget Sound	.....	.....	.....	.....	.....	.....	Pro.	Bldg.	14000(d)
Total built	.....	.....	.....	20000	20000	50000	90000	104000	153000

Pro.—Projected. Bldg.—Building

(a) Formerly Bradford, R. I.

(b) 14,000 additional tons authorized but no land available.

(c) 35,000 tons planned and partially appropriated for. Not started.

(d) 21,000 additional tons authorized and to be built.

TABLE III.—OIL CARGO VESSELS—U. S. NAVY

Ship	Type	Authorized	Commissioned	Speed	Capacity
Arethusa	Oiler	Purchased	1898	10.0	4,517
Kanawha	Oiler	22 Aug. 1912	5 Jun. 1915	14.0	7,455
Maumee	Oiler	22 Aug. 1912	17 Apr. 1915	14.0	7,455
Cuyama	Oiler	3 Mar. 1915	.....	.....	.....
Brazos	Oiler	29 Mar. 1916	.....	.....	.....
Jupiter	Collier	13 May 1908	7 Apr. 1913	14.0	3,075
Cyclops	Collier	13 May 1908	7 Nov. 1910	14.0	2,925
Neptune	Collier	3 Mar. 1909	20 Sept. 1911	13.0	2,925
Proteus	Collier	24 Jun. 1910	9 Jul. 1913	14.5	3,050
Nereus	Collier	24 Jun. 1910	10 Sept. 1913	14.5	3,050
Orion	Collier	4 Mar. 1911	29 Jul. 1912	14.5	2,575
Jason	Collier	4 Mar. 1911	26 Jun. 1913	14.5	2,575

SUMMARY.

TANKER CARGO CAPACITY IN COMMISSION.

As of 31 December.

	1911	1912	1913	1914	1915	1916
14-knot colliers	2925	5500	17250	17250	17250	17250
14-knot tankers	.....	.....	.....	.....	14910	14910
14-knot total	2925	5500	17250	17250	32160	32160
Slower vessels	7442	7442	7442	7442	7442	7442
Total capacity	10367	12942	24692	24692	39602	39602

TABLE IV.

Type Status	1911	1912	1913	1914	1915	1916
Destroyers built	15	21	25	29	36	44
Destroyers authorized and building	14	14	16	18	17	29
Auxiliary oil burners built	4	6	6	8	8	8
Auxiliary oil burners building	4	2	2	0	0	0
Oil burners built	0	0	0	0	0	4
Oil burners building	0	2	3	4	7	4
Others built	1	1	1	2	5	6
Others building	0	0	3	4	4	3
Oil used, M. bbls.	137.6	336.8	361.8	488.5	521.4	842.5
Oil used, equivalent coal (factor 0.21) M. tons	28.9	70.7	76.0	102.6	109.5	176.9
Coal used, M. tons	744.4	729.9	658.8	714.8	790.7	802.2
Per cent oil	3.8	8.8	10.3	12.5	12.1	18.1

be credited with having fully studied and made recommendations concerning the two questions of tankers and shore storage. In the two and one-half years of European war during which we were given the opportunity to prepare for our share in the general conflict, a thorough logistic study was made and war plans drawn up. Admiral McGowan, seconded by the General Board, continually urged expansion of the Navy's fuel oil storage and transportation facilities. The tables above show the inadequacy of the accomplishment.

A study of Table II reveals that the distribution of the Navy's shore storage was excellent. This is undoubtedly due to the fact that the Secretary had been free, for several years, to follow the recommendations of the General Board as to the location of tankage. The tankage was adequate for the base operations of the fleet as long as tanker transportation was adequate to keep the storage filled. However, the latter function was necessarily allotted to commercial vessels and since these were entirely owned or controlled by the oil companies, the Navy found it necessary to purchase most of its supply delivered into naval storage and the additional price had to be paid. The Navy also faced the prospect of having the availability of commercial tankers curtailed due to more profitable demand in other trade.

With the dependence for fleet supply at advanced bases on the seven colliers and two tankers with a capacity of only 35,000 tons or 10 million gallons, it is probable that any distant operations of the fleet would have been somewhat restricted.

7. NAVAL FUEL OIL BOARD.

The crowning event of the pre-war period was the investigation conducted by the "Naval Fuel Oil Board."

On 15 April, 1916, the Engineer-in-Chief, Admiral R. S. Griffin, wrote to the Secretary of the Navy as follows:

FROM: BUREAU OF STEAM ENGINEERING.

To: Secretary of the Navy.

Via: Chief of Naval Operations.

Subject: Board on the Supply of Fuel Oil for the Navy.

1. The question of the supply of fuel oil for the fleet is of such great importance that the Bureau believes that it should be taken up and seriously studied at once in order that the necessary information may be had as to the cheapest fuel oil that may be used, the quantity and location of storage that should be provided, the methods that should be adopted for providing the current supply, and the plans that should be formulated and followed in order that the Navy may be assured of an adequate future supply and in order that the Navy Department may intelligently and safely continue its policy of building oil-burning vessels.

2. The Department of the Interior estimates that there remains in the oil fields of the nation a supply for only twenty-five years, and a recognized authority on this subject states:

"In the exhaustion of its oil lands and with no assured source of domestic supply in sight, the United States is confronted with a national crisis of the first magnitude. * * * We must either plan for the future or we must pass into a condition of commercial vassalage, in time of peace relying on some foreign country for the petroleum wherewith to lubricate the highways of commerce, in time of war at the mercy of the enemy who may either control the source of supply or the means of transportation."

3. At the present time no one is charged with the responsibility of seeking a solution of the question of an adequate future supply of oil fuel, and the sole responsibility of this Bureau in the matter, as defined in the Navy Regulations, is to "inspect all fuel for the fleet."

4. The subject has never received the attention and serious study that it deserves, and unless adequate measures are soon taken the Navy will surely awaken some day to the realization that it has a fleet of oil-burning vessels with no adequate means for supplying that fleet with the only fuel it can use. If this day should come, the responsibility for this neglect would certainly be fixed upon the Navy Department as a whole and upon every Secretary of the Navy since the policy of building oil-burning vessels was adopted.

5. In view of the above, it is earnestly recommended that a Board of Officers, headed by an officer of high rank, be designated for the sole duty of studying this question in all of its details and making recommendations as to the method of solving this problem.

6. It is further recommended that the sum requested for the examination of the feasibility of establishing a refining plant be increased, if possible, to $10,000, and that this sum be expended in connection with the work of the Board herein recommended.

(signed) GRIFFIN.

The following memorandum and endorsement were made on the above letter:

"Order the Board. Matter of recommending $10,000 will be taken up later."

(signed) JOSEPHUS DANIELS.

1ST ENDORSEMENT.

APRIL 25, 1916.

From: Chief of Naval Operations.

To: Bureau of Navigation.

Subject: Board on the Supply of Fuel Oil for the Navy.

1. It is directed in accordance with the above that the Board recommended herein be ordered, Board to consist of Rear Admiral John R. Edwards, U. S. N., Lieutenant Commander John Halligan,

U. S. N., Lieutenant Commander J. O. Richardson, U. S. N., and Passed Assistant Paymaster James C. Hilton, U. S. N.

2. The Bureau of Steam Engineering will suggest a precept covering the Board's activities.

3. Attention is called to the memorandum of the Secretary of the Navy in reference to paragraph 6.

(signed) W. S. BENSON.

Based on the further recommendations of the Bureau of Steam Engineering, the precept issued to the Board on 9 May, 1916 ordered an investigation and report on the following points:

a. The lowest priced fuel oil that will meet the needs of the Navy.

b. The specifications under which the supply should be purchased.

c. The source of this supply which should be depended upon.

d. The methods of securing the current supply.

e. The plan that should be adopted to provide for the future needs of the Navy.

f. The plan that should be adopted to insure an adequate reserve supply.

g. The amount, kind, location, and estimated cost of storage that should be provided.

h. The amount and kind of fuel ships and barges that should be provided, and

i. Any other points that may be disclosed by the investigations of the Board.

The Board rendered two reports. An interim report submitted on 21 September, 1916, was signed by Rear Admiral Edwards, Lieutenant Commanders Halligan and Richardson, Passed Assistant Paymaster Omar D. Conger, members, and Lieutenant Fred W. Milner, U. S. N., retired, member and recorder, indicating some changes in membership from the original precept. The interim report carried two recommendations:

1. That areas of the public domain containing oil shale deposits be set aside as naval reserves; and

2. That an additional naval petroleum reserve be set aside in the Osage Indian Reservation.

The final report was submitted on 22 December, 1916, and bore the same signatures as did the interim report with the exception of that of Admiral Edwards. From the beginning of his connection with the fuel oil problem, Admiral Edwards had considered that the question of furnace volume was the primary one which would determine the efficiency of oil-burning. As senior member of the Board he recommended that an investigation of furnace volume be made at the Fuel Oil Test Plant by the Board. This recommendation was not consistent with the precept of the Board nor with the intentions of the Bureau of Steam Engineering in suggesting the investigation on supply. Admiral Griffin recommended that the precept be changed by deleting paragraph "i," thus leaving only specific instructions. This was done.

On 22 September upon completion of the interim report, Admiral Edwards was detached from duty on the Board and the senior membership devolved upon Lieutenant Commander Halligan.

The final report was approved by the department and circulated to the various interested bureaus for their information and compliance with recommendations insofar as was practicable. In submitting the report the Board evidently contemplated that a continued development period was to be allowed the Navy. This was not actually realized because within four months after the approval of the report, the United States entered a state of war which permitted of no orderly development.

The "Summary of the Conclusions of the Board" is quoted in full below:

"Oil as a fuel in vessels of military importance, when compared with coal, yields advantage in design and operation which constitute a distinct superiority of type. This superiority is so marked that petroleum must be used as the principal fuel of the fleet. Ships designed for oil cannot, without extensive rebuilding, be converted for coal-burning.

"For the use of the Navy it is estimated that there will be required, in time of peace, oil in quantities increasing from 842,000 barrels (117,880 tons) during the present fiscal year, to 10,000,000 barrels (1,408,450 tons) annually in 1927. In time of war this consumption will be increased at least threefold. For air-craft and for industrial processes associated with National Defence there

will be required additional quantities of oil which cannot be estimated by this Board.

"The supply of petroleum which the U. S. Geological Survey estimates to be contained in pools within the continental limits of the United States is twenty-eight times the present annual consumption.

"If we depend upon the domestic petroleum market for our supply of fuel oil the cost, already from two to three times that of coal in the Atlantic Ocean, will rapidly increase to a prohibitive figure, and in the near future the extent of this supply in time of war will not suffice for the needs of the fleet.

"Thus there exists a condition of serious import affecting the National Defence. It is necessary that measures be instituted that will—

"*a.* Insure an adequate and dependable reserve of oil for the future use of the Navy.

"*b.* Control the cost of oil to the Navy.

"Mexico and the Caribbean littoral will furnish most of the oil to be burned in the Atlantic. It may be necessary that the Navy adapt its equipment to this oil, which is more viscous than that now used. This source of oil will be denied us in time of war if we lose control of the sea.

"The only method of insuring an adequate and dependable reserve of oil which will be available in time of war to the Navy is by holding in unassailable ownership reserves of United States lands with sufficient petroleum content. The ability of the Government to hold such reserves after they have become attractive to corporations is threatened by pending legislation. The Navy cannot be assured of a dependable reserve supply of oil until the Congress declares definitely the immunity of Naval Petroleum Reserves from adverse legislation.

"Existing Naval Petroleum Reserves are in California and Wyoming. They are remote from the Atlantic seaboard, and it is necessary that a source of supply be constituted in fields connected by pipe line to the East Coast. For this the western half of the Osage Nation, in Oklahoma, is suited, and the Board has recommended that a Commission determine a method whereby the Navy may control a suitable area of these lands.

"To provide for the distant future, when the underground supply of petroleum will have been exhausted, it is recommended that there be constituted a reserve of public lands containing oil shales which are now comparatively without value. Such a reserve should not be considered in any sense a substitute for Naval Petroleum Reserves Numbers 1, 2, and 3.

"The excessive cost of fuel oil in the Atlantic is due to the following conditions:

"*a.* By reason of the Navy's lack of adequate equipment for transporting, stowing, and handling the oil, competition has necessarily been limited to the few large companies possessing such equipment.

"*b.* Due to lack of storage tank capacity, the Department is unable to take advantage of the marked fluctuations in the petroleum market, which, in the cost of a given quantity of oil in one year, may be greater than the cost of tanks to hold the oil.

"*c.* A large portion of the cost of oil in the Atlantic is due to transportation. The cost of chartered transportation has always been at least twice that of transportation in naval tankers, and at present is six times as expensive.

"Existing fuel oil tankage is not of sufficient capacity to provide for the needs of the fleet. Considering the quantity of oil which will be used by the Navy in the near future, the tankage now built, or authorized to be built, is wholly inadequate. Military and economic conditions require that there be constructed tanks or reservoirs to provide storage for twice the annual consumption. There is required to be obtained from this Congress an appropriation for constructing tankage to hold 300,000 tons of oil.

"While oil-carrying vessels now under American registry are sufficient in number to provide for the needs of the Navy in time of war, it is probable that a large number of them will be transferred to foreign registry after the war. The Board therefore urges the construction of naval tankers in numbers requisite for the needs of the fleet. In addition to those required in the Train, the Board recommends that there be completed by 1919 four naval tankers to carry oil from Gulf ports to the Atlantic Seaboard.

"The Board recommends the construction of a topping plant on deep water in the lower Chesapeake, of a capacity to provide

one-fifth the estimated consumption of the fleet in 1919. By purchasing crude oil at a Mexican port, transporting it in naval tankers, and removing the gasoline and kerosene, fuel oil can be produced at a net cost less than one-third the present cost. The advisability of constructing this plant is suggested by the following considerations:

"*a.* The Navy as a large consumer needs an intimate knowledge of processes of refining, in order that it may control the cost and intelligently write specifications. The analogy of the smokeless powder factory at Indian Head, Maryland, is cited.

"*b.* Various grades of crude oil may be purchased as market conditions warrant, and converted into fuel oil, gasoline and lubricants of the specific qualities best suited to naval use.

"To render effective the recommendations of the Board there is required the following action by the Navy Department:

"*a.* A continuous vigorous resistance to the efforts of private and corporate interests who seek to destroy the Navy's title to its Petroleum Reserves.

"*b.* To secure the appointment by Congress of a commission to determine the conditions under which the Navy may secure control of an area of oil lands in the western half of the Osage Nation.

"*c.* Provision in this year's Naval Bill for oil storage tanks of 300,000 tons capacity. The determining of the location of this tankage.

"*d.* The building or purchase prior to 1919 of four oil tankers, each of a capacity of 7500 tons, in addition to those now contemplated.

"*e.* The selection and purchase of an area of 1000 acres as a site for a Naval Topping Plant, and authorization by Congress for such a plant."

The "Summary" did not contain recommendations which were discussed in detail in the six appendices of the report. The subjects of these appendices are:

a. Estimated consumption of fuel oil by the fleet, based on the then existing building programs, and computed by the Board.

b. Same as *a* but computed and submitted to the Board by the Bureau of Supplies and Accounts.

c. A curve of the world's and United States' production of petroleum from 1860 to 1915.

d. A discussion of the question of fuel oil specifications.

e. A list of all bulk oil carrying vessels under United States registry.

f. A detailed plan for the construction of the Navy topping plant recommended by the Board.

Of the six, only appendix *d* is of particular interest. It was especially intended for the Bureau of Steam Engineering as a basis for the development of fuel oil specifications. It is quoted below in full:

NAVAL FUEL OIL BOARD REPORT.

APPENDIX "D."

U. S. NAVAL FUEL OIL BOARD.

1. The Naval Fuel Oil Board was ordered primarily for the purpose of studying the question of the *supply* of fuel oil for the Navy, and was directed to submit a report covering the following points, in addition to many others:

a. The lowest priced fuel oil that will meet the needs of the Navy.

b. The specifications under which the supply should be purchased.

c. The source of supply which should be depended upon.

2. On taking up this work, it is believed that the following points have already been determined:

a. Mexico will eventually be the source which must be depended upon for bulk of the supply of fuel oil.

b. Some system of mechanical atomization will always be used, because the other systems either waste fresh water or require additional machinery weight.

c. The oil used must be free from gritty fibrous or other foreign matter, because none but fairly clean oil can be successfully burned for long periods with mechanical burners.

d. The oil must never be heated above its flash point in any part of the system except the burner, because it is considered unsafe when pressures up to 300 pounds per square inch are used on the system.

e. To efficiently burn any oil its viscosity must be reduced to at least 8 Engler and any clean oil can be burned when reduced to a viscosity of 8 Engler. This has been determined by many tests at the Fuel Oil Testing Plant and elsewhere.

f. In view of *d* and *e* above, the flash point of fuel oil for the Navy must be higher than the temperature at which the oil has a viscosity of 8 Engler.

g. The maximum temperature to which fuel oil may be heated in order to deliver it to naval vessels is 90 degrees F. because of the proximity of the fuel oil tanks to the magazines on board ship.

3. The first point to be determined is:

How viscous may an oil be and yet permit the pumps ordinarily used at storage tanks and on barges and tankers to deliver their rated capacity?

Experiments along this line have been conducted at the Fuel Oil Testing Plant, but they were not complete so that, unless the information is already available from some other source, pumping tests on a very heavy viscous oil should be conducted with a representative pump and arrangements and a curve drawn showing delivery in gallons per hour as abscissae and viscosity as ordinates. On these tests the power required should also be measured.

From this curve can be taken the viscosity "V" corresponding to the rated capacity of the pump. Of course, with a reduction of the viscosity the pump would deliver more than its rated capacity.

With the above determined viscosity, one clause of the specification is determined, namely: The viscosity at 90 degrees F. shall not be greater than "V" Engler.

4. If the suction qualities of the pumps installed on board naval vessels are equal to or better than those installed at storage tanks and on barges and tankers, then these pumps can handle the oil at a viscosity of "V" Engler, but it would probably be better to determine by experiments.

How viscous may an oil be and yet permit the suction (booster) pumps ordinarily installed on naval vessels to supply an adequate quantity for full power?

At the Fuel Oil Testing Plant pumping tests were made on a Blake simplex 6-inch × 6½-inch × 13-inch pump, of the type in ordinary use in service, taking a suction with an 8-foot lift through 10 feet of 3-inch pipe bushed down to 2½ inches at the pump. These tests showed that the amount required for full power, 564 gallons per hour, could be pumped when the oil was reduced to a viscosity of 375 Engler.

It is believed that this viscosity, 375 Engler, should not be accepted as the answer to the above question without additional tests or confirmation. Therefore, unless the information is already available from some other source, pumping tests on a heavy viscous oil should be conducted with a pump and arrangement duplicating the installation on board ship and a curve drawn showing delivery in gallons per hour as abscissae and viscosity as ordinates. On these tests the power required should also be measured.

From this curve can be taken the viscosity "Y" corresponding to the amount of oil required per hour for full power.

5. The next point to be determined is—

With oils having a viscosity of "V" Engler at 90 degrees F., what is the temperature of these oils when they have a viscosity of "Y" Engler?

To determine this point it will be necessary to submit to viscometric examination various oils having a viscosity of about "V" Engler at 90 degrees F. and to trace the temperature viscosity curves of these oils. From these curves the maximum temperature "T" required to reduce any of these oils to a viscosity of "Y" Engler can be determined. Then the heaters of the service tanks must be capable of maintaining a temperature of at least "T" degrees at the suction of the booster pumps when the pumps are taking the amount of oil required for full power.

6. The record of ocean temperatures, for the month of February shows that temperatures of 31 degrees to 39 degrees F. may be expected off New Foundland, therefore, the next point to be determined is:

Using steam at 250 pounds per square inch, how many square feet of heating surface are required in the oil heaters of a service

fuel oil tank to maintain a temperature of "T" degrees at the suction when the surrounding sea water is 31 degrees F., the oil being drawn off at the maximum rate required for full power?

This information may be obtained by pumping and heater tests on board ship using fuel oil having a viscosity of "V" Engler at 90 degrees F. and pumping the oil from the tank at the rate required for full power with the ship moored at the Navy Yard, Philadelphia, where, in the winter time, the temperature of the water is frequently 32 degrees F. and where the current in the river will change the water surrounding the ship, thereby simulating conditions with the ship under way in cold water.

The data from these tests would give a curve of gallons of oil per hour on square feet of heating surface, with steam for heater at a pressure of 250 pounds per square inch, the initial temperature of the oil and the surrounding water 32 degrees F. and the final temperature of the oil "T" degrees.

If "Q" is the number of gallons per hour required for full power, then from the above curve, take off "N" the number of square feet corresponding to "Q" and "N" represents the minimum number of square feet of heating surface allowable for the heaters of the service tank under test.

It is possible that after determining "T" and "N" as above that it may be considered advisable to maintain the temperature of the oil at the suction of the booster above "T" degrees, say at "S" degrees, in order to reduce the amount of heating required in the pressure heaters and the work of the booster pumps. In this case the tests outlined in paragraph 6 or similar tests will give the amount of heating surface required for the service tank dealers.

7. The next point to be determined is:

With oils having a viscosity of "V" Engler at 90 degrees F., what is the temperature of these oils when they have a viscosity of 8 Engler?

From the curves developed by the procedure outlined in paragraph 5, it is possible to take the maximum temperature "U" required to reduce any of these oils to a viscosity of 8 Engler. Then the pressure heater must be capable of maintaining a temperature of at least "U" degrees at the discharge from the heater.

8. *When using steam at 250 pounds pressure per square inch, how many square feet of heating surface are required in the pressure heater to maintain a temperature of "U" degrees at the discharge from the heater when the entering oil is at a temperature of "S" degrees, and oil is being delivered through the heater at the maximum rate required for full power?*

This information may be obtained by pumping and heater tests using full oil having a viscosity of "V" Engler at 90 degrees F. maintaining the temperature of the oil entering the heater at "S" degrees, the steam pressure on the heater at 250 pounds per square inch, the temperature of the oil discharge from the heater at "U" degrees, and varying the amount of heating surface by plugging the tubes. With the data secured a curve could be drawn showing gallons of oil per hour on square feet of heating surface. From this curve take "M," the number of square feet of heating surface corresponding to the amount of oil required per heater for full power.

9. With the information already available and that secured by the above outlined tests it will be possible to completely cover points *a*, *b* and *c*, and draw the following satisfactory specifications:

1. Fuel oil to be a hydrocarbon oil free from grit, acid, fibrous, or other foreign matter likely to clog or injure the burners.

2. The flash point not to be lower than 150 degrees F. and to be higher than the temperature at which the oil has a viscosity of 8 Engler.

3. The viscosity not to be greater than "V" Engler at 90 degrees F.

4. The water and sediment not to exceed 1 per cent.

NOTE: The oil to be delivered to a naval vessel at a temperature greater than 90 degrees F.

In addition to this, the above tests will give valuable information for use in the design of service tank heaters and pressure heaters."

The formal report of the Fuel Oil Board did not constitute its only contribution to the cause. During its existence the Board discussed various questions with practically everyone in the United States, with either Government or commercial connections, who was in a position to give it any technical information or advice.

One of these questions was that of reducing the viscosity of the heavy Mexican residual fuel oil other than by heating. This was submitted to the Bureau of Mines, whose report was not rendered until after the Board had been dissolved. The report, received by the Bureau of Steam Engineering, stated that two different methods of reducing viscosity had been investigated and the resultant recommendations were:

"It is suggested that to bring Mexican oil within Navy Department specifications it be mixed with fuel oil distillate, the mixing to be done in open tanks heated by steam under pressure till the oil layers have blended thoroughly and have attained a uniform temperature, probably between 120 degrees and 130 degrees C.

"Specific conditions as to the quantities used will be regulated by the properties of the Mexican oil and the fuel oil distillate. The temperature to which it must be heated depends largely on how high a flash point is desired.

"The method of reducing viscosity by distilling off a portion with cracking and mixing back with residuum is undesirable because the cracking causes carbon deposit and forms pitch material not readily soluble in petroleum oils."

The Bureau had just requested Operations to assign a destroyer to coöperate with the Fuel Oil Test Plant to study the necessary equipment changes necessary to permit the use of very viscous fuels. Since the Bureau of Mines report was conclusive that viscosity could be reduced by blending, it was decided that the destroyer should be utilized for testing the blend theory rather than for the investigation of handling more viscous fuel oils. The problem was laid down but its consummation ran over into the war period and will be discussed in the next section.

When the appropriation for $60,000 mentioned previously was made the Board was in session and made the following recommendations (abstracted and not quoted):

a. That all subjects covered in the bill were being handled by the Board except:

1. Investigation of gasoline, and
2. Economic availability of the fuel oil supply from the reserves.

b. That the gasoline question had been well covered by reports of the Department of the Interior and the Federal Trade Commission and that all that was required was "a technical investigation to standardize the specifications under which gasoline for special purposes is purchased." It was stated that such an investigation was beyond the scope of the Board.

c. That the study of the availability of the fuel oil supply from the Reserves be handled by the Officer in Charge of Naval Petroleum Reserves in California, Lieutenant Commander Landis, and that if he needed additional funds these be provided from the appropriation.

d. That $15,000 be allotted to the Fuel Oil Test Plant as its share of the appropriation for purchases of equipment and plant extension.

e. That $25,000 be allotted for the purpose of drilling a test well in Reserve Number 3.

The orders issued to Landis as a result of recommendation *c* have already been mentioned.

Coincidentally with its report on 22 December, 1916, the Board, through its senior member, submitted the additional recommendation quoted below from a letter to the Secretary of the Navy:

"The Board recommends that those elements of fuel supply for the fleet not now charged to other agencies under the Department, in particular those pertaining to lands containing fuel reserves, be assembled under an officer of experience whose office shall be recognized in the organization of the Navy Department."

The bald summary of the Board's conclusions have been quoted above. No comment will be made at this time. During later portions of this history reference will be made to the Board's recommendations which for convenience are skeletonized below:

a. Clearly and firmly establishing the Navy's title to Petroleum Reserves 1, 2, and 3.

b. Acquisition of an additional petroleum reserve in the Osage Reservation of Oklahoma.

c. Acquisition of areas of oil shale bearing lands as naval reserves.

d. Construction of a Navy refinery on Chesapeake Bay.

e. Construction of Navy fuel oil storage to bring the total capacity to twice the annual consumption of the fleet.

f. Construction of an adequate tanker fleet both for supplying the fleet and for maintaining full storage tanks.

g. An investigation into practicable methods of reducing the viscosity of fuel oil.

h. An investigation into the actual value of Reserves Numbers 1, 2, and 3.

i. Establishment of an office recognized in the organization of the Navy Department to take charge of those elements of fuel supply not already charged to some bureau or office.

8. SUMMARY OF CONDITIONS AT THE END OF THE PRE-WAR PERIOD.

Utilization:

The Navy entered the war with the Fuel Oil Test Plant in operation under experienced personnel. This plant had been and was being used for the test of fuel oil equipment and of the fuel itself and for the training of naval personnel in the burning of fuel oil.

Quality:

Tests had been completed which indicated the necessity for making some modifications in the fuel oil equipment of vessels to permit them to handle the heavier fuel oils which were becoming a serious problem in connection with fuel oil supply. A request for the detail of an oil-burning destroyer to work with the Fuel Oil Test Plant in a study of the equipment changes needed had been changed to a study of the use of fuel oil blends. The request was pending.

Application:

The fleet was in the transitional stage in the shift from coal to oil. Oil had been definitely adopted as the only fuel for all new construction, but a few destroyers, most of the battleships, and practically all other ships were still coal-burning.

Source:

The Navy was depending entirely upon commercial sources for its fuel oil supply. Areas of the public lands in California and

Wyoming withdrawn from entry had been designated as Naval Petroleum Reserves. The title of a major portion of these reserves was still in dispute and legislation was pending which would lead to a settlement of the dispute. Money was available for determining the value of the reserves and Lieutenant Commander Landis was on duty in California in connection with all matters pertaining to the reserves.

Supply:

There had been no difficulty of supply until the European war dislocated shipping to the point where it was very difficult to contract for fuel oil to be delivered at the desired points. The supply was plentiful and the price low at the refineries. The Navy was without sufficient tank steamers to handle the situation in the most effective way. It was also deficient in shore storage, sufficient of which would permit of buying at low prices and holding for later use as well as to carry the Navy over in case of a supply curtailment.

Distribution:

The Navy had well distributed but inadequate shore storage facilities and very inadequate mobile storage for servicing the fleet on distant operations. The building program for both shore storage and tankers had progressed very slowly. The need for both was thoroughly recognized by the Navy Department but the necessary authorizations and appropriations from Congress were far behind those recommended by the Department. It must be recognized, however, that no real steps toward preparedness in any of the other respects was taken by Congress until late in 1915 and actual results naturally lagged far behind legislative action.

General:

The Navy Department had in its hands a most complete and thorough report based on an investigation conducted by a board of officers, the two senior members of which had been active in advance in fuel oil since their service youth. The recommendations of this board were sweeping but they could have been followed had normal development not been interrupted by rapid war preparations and very shortly thereafter by hostilities.

DISCUSSION OF THE STEEL CASTING SITUATION.

By F. A. Melmoth.*

The report of the visits of Captain Louis Shane, U. S. N., to a number of European foundries appearing in the Journal of the American Society of Naval Engineers for February, 1933, and the impressions and conclusions resulting, have proved of particular interest to me. This is largely because I have been privileged to see both sides of the picture, being a metallurgist who has had charge of steel foundries in England for a good many years and later operating in a similar capacity in the United States. I am aware of the impression gathered by European visitors on the occasion of their visits to steel founding plants in this country, and, with an inside knowledge of a number of European plants, it is intriguing, to say the least, to follow carefully the impressions of a visiting American, trained to observe, to European producing plants.

Firstly, in order to remove any possible erroneous conclusions which could incorrectly be derived from some of my later statements, let me say at once that I appreciate Captain Shane's balanced judgment; that I believe the European case was honestly presented to him in those foundries which he visited; and that the whole report and associated discussions constitute a helpful and inspiring addition to the literature dealing with steel castings.

Having said this, in order to avoid being misunderstood, I wish to add that it would be necessary to go very much farther, and use a much greater number of cases, in order to arrive at a completely sound appraisal of European and American ability and success in steel castings manufacture.

I should also like to say at once, and without equivocation, that steel casting problems are one and the same thing on either side of the water. The degree of success is essentially similar, and varies,

* Mr. Melmoth was intimately associated with several Steel Foundries of Scotland and England prior to his present association with The Detroit Steel Casting Company.

as one might expect, from plant to plant; consequently, to appraise accurately, one would need knowledge of all plants, or, at any rate, of a majority.

The class of work being produced varies markedly from plant to plant, and we in the business know full well that success with one type of work does not predicate equal success with another type.

No production operations or series of operations in industry offer more opportunity for variation in the human factor than do those associated with castings production; and this goes for the whole gamut, from designer to final inspection. It is obvious, therefore, that familiarity, in this case breeding not "contempt," but facility, mental and physical, and a right judgment in the avoidance of pitfalls, accounts for this variation of ability on individual classes of work.

It follows, then, that Captain Shane would need to compare performances of similar types—a rather difficult matter.

As regards the criticism on the speed of American steelmaking methods, this is a bearded ancient among us Europeans. Personally, I feel we have overdone it. Heavy power or fuel imputs during the melting period are not only economical, but quite conceivably sound metallurgical practice, for many reasons out of place to argue here. In finishing the heat, the reasoning is sound that time is an important function, but, so far, my experience suggests that American steel founders in general fully appreciate this and act accordingly. It must be conceded that the final evidence of steel quality, as at present accepted, being the results of the tensile test as a whole, such results are quite equal, to say the least, in the American product when compared to the European. Hasty, ill-advised scamping of the finishing operation in steelmaking would most decidedly show itself in the demonstrated test results.

In fairness, then, we must look farther afield for our shortcomings than furnace practice.

From the viewpoint of molding sand, America possesses a vast supply, and of a nature sufficiently varied to allow the maximum of choice when considering suitability for the work in hand. We certainly do not possess, so far as I know, an American substitute for the European "Compo," or for the "Chamotte,"* which is the

* The Editor's attention has been invited to the fact that several native fire clays are of the same chemical composition as "Chamotte."

base for Compo in parts of Central Europe. It is doubtful, however, if it is necessary that we should do so. I have seen hundreds of large castings in this country, produced in specially designed sand mixtures, just as fine in appearance and soundness as those commonly produced in Compo in Europe. It is arguable that the value of Chamotte, or any advantages that it may confer, are not so much on account of its chemical composition as on account of the definite grading of size in its production for the variety of jobs produced.

On the use of chills, opinions vary widely. Their use calls for great discussion, particularly if of the internal type. I am not enamored of the idea of trying to save metal in feeding heads, by inducing solidity by the overuse of internal chills, which, even if they fuse to the parent metal, still result in a lack of homogeneity. Why insist on longer steelmaking cycles to produce homogeneity, and then destroy it by sticking in the steel a lot of material, often of doubtful origin, which, if it did thoroughly melt and blend with the steel, would necessarily fail in its intended purpose? Why not admit that the use of these internal chills often constitutes a reproach to the designer, and get him to so appreciate the vagaries of metal solidification, that he avoids the necessity? Too often is the foundryman driven to expedients in which he himself has little faith, and often of which he has a pronounced fear, in order to overcome a perfectly natural manifestation of the metal he is using which could be placed under complete control by design.

I am well acquainted with the Letchworth, England, foundry Captain Shane refers to. Under the able direction of Mr. Deschamps, this plant has a great reputation for the quality of its Converter-produced steel. Still, I would not evaluate Converter steel as a whole by my acceptance of the excellence of this plant's product. Neither am I prejudiced in favor of electric furnaces. As the years go by, most of us in the steel casting business realize that no steelmaking method has the slightest chance of becoming a panacea for the ailments of steel castings. We *know* that design, however, offers tremendous possibilities. After all, the customers of the steel castings industry are buying castings, and not merely pounds of steel.

In other words, a casting of indifferent Converter steel, so designed as to be made sound and homogeneous, has an infinitely greater chance of giving satisfactory service than would one of highly expensive, slowly produced, de luxe material, of such design as to preclude the obtaining of intrinsic soundness.

Heat treatment of a controlled type is admitted to be an essential for almost all castings made in this country. I have found no less insistence on this in America than in Europe. American heat treatment equipment, as a whole, is of a more advanced type, and, from this standpoint, the domestic product should, and I believe does, receive at least equal care and attention.

The personnel of many American foundries is most certainly, nowadays, not of lower caliber than that of our European prototype. An attendance at the technical sessions on steel founding, of the American Foundrymen's Association, would demonstrate, without any argument, that scientific thought is now in the saddle. Many men of metallurgical and engineering attainment represent the control of steel foundry operations, technical problems are hotly and energetically discussed, and, most certainly, no one advocates or upholds the old rule of thumb policies of production at one time existing. We all want to know why these things happen, in order to avoid them.

I should not wish to have Captain Shane cherish the idea that superficial welding is not carried out in European foundries. It most certainly is. Usually, it is very good welding, a most important matter. The British Admiralty does not, or did not, up to three years ago, entirely prohibit welding on steel castings. It insists, however, that all superficial defects shall be fully and honestly submitted to its representatives, and their approval obtained for any repair operations. A manufacturer with a reputation to maintain would not submit a casting containing an obvious serious defect, for his own sake, but permission is obtainable, where the defect is trivial and does not in any way affect serviceability.

May I suggest to Captain Shane that it is not this type of defect which is liable to occasion trouble in service. It is the deep-seated, invisible type, present due to design, and whose effect is steadily increasing under the strains of service conditions.

Finally, will Captain Shane permit me, as a metallurgist whose lines have fallen into the problem-littered pathways of the steel castings industry, and who had some little experience on both sides of the water, to give him my honestly held, convinced opinion, entirely free from national prejudice, or any other influences, as to the causes of trouble in steel castings?

1. America is not training her molding operatives on the established lines of Europe. Frankly, therefore, I do not believe that the moulding skill of the American artisan is the equal of his European prototype.

2. Machine-produced castings in this country, the result of planning and controlled production, with the human factor of less vital importance, are as good here as anywhere, and in some cases better.

3. Metallurgists and engineers are just as common in American steel foundries, and are often more greatly valued.

4. Steel quality is not the answer to the steel castings riddle, neither is speed of production, correctly allocated, the controlling factor of steel quality.

5. American molding materials are even more controlled than is the case in Europe.

6. More serious and promising investigation is proceeding here in steel casting complexities than in Europe.

7. Get at the question of design to suit the characteristics of the material, bring the foundryman into the picture as a man with a brain and a spirit of helpful partnership when the job is in the embryonic stage, don't be afraid to be utterly unorthodox in design (the very fact of the necessity for this discussion proves the orthodox is wrong), and infinitely better castings will accrue to you at once.

A steel ingot is a casting of controlled shape, and general design, to permit controlled solidification. Just so far as we, in our designs for casting, approach, or recede from solidification control by design exigencies, so far have we to reach out into the indefinite gambling distance for the perfect steel casting.

SOME NOTES ON E.H.P. CALCULATIONS AND PROPELLER CHARACTERISTICS.

By Henry F. Schmidt, Civil Member.

One factor which has been neglected in calculating the E.H.P. for the full-sized ship from model basin tests is the power required to accelerate the circulating water from rest to the ship's velocity.

The writer has not been able to find any reference to this part of the total power in any published works on ship resistance or model basin research.

In slow-speed ships of low power, the circulating water factor may safely be neglected, but, as will be shown, in high-power fast ships, it may amount to five per cent or more of the E.H.P.

Because of the relatively higher skin friction in models than in full-size ships, an attempt to determine the drag caused by the acceleration imparted to the circulating water would give a result much too low. It is fortunate, therefore, that this can be calculated as follows:

If V is speed of ship in knots,
Q is the gallons of water per minute
and one gallon sea water weighs 8.6 pounds,

then the energy imparted to the water per second, as it is discharged overboard with little if any sternward velocity, is

$$\frac{Q}{60} \times 8.6 \frac{\left(\frac{6080\ V}{3600}\right)^2}{64.4} = \frac{QV^2}{157}$$

and the theoretical E.H.P. is

$$\text{E. H. P.} = \frac{QV^2}{550 \times 157} = \frac{QV^2}{86{,}400}$$ or if E_p is the propulsive efficiency, the theoretical

$$\text{S. H. P.} = \frac{QV^2}{86{,}400\ E_p}$$

Owing to the circulating water being drawn into and discharged from the ship, the stream lines are seriously disturbed, resulting in a drag which is greater than the theoretical, which must be multiplied by a factor f to obtain the actual power.

The difficulty of the relative effect of skin friction between model and ship can be avoided by testing the sea chest or scoop in air and determine the factor by which the theoretical drag must be multiplied to obtain the actual drag, since the factor thus obtained is independent of the size or medium.

The writer made some tests in which scoops of standard parallel tube and divergent tube types were held in a plate as in Figure 1.

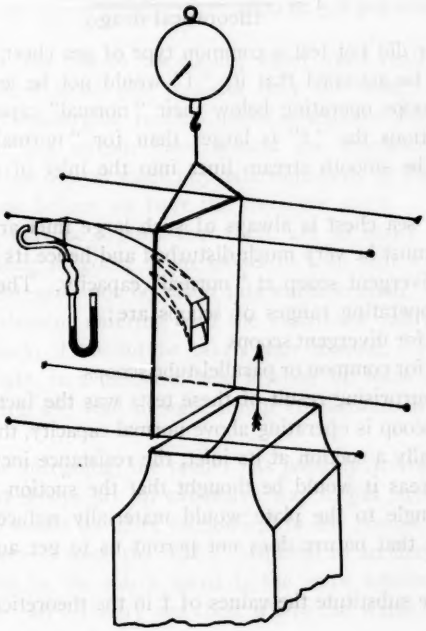


FIGURE 1.

The scoop discharge was carried around at right angles to the face of the plate so that the reaction from the discharge could not affect the result. The plate was held in a vertical plane by small

wires and was supported by a scale so the decrease of weight due to the drag could be determined. The jet velocity was determined by an impact tube and the volume of air entering the scoop was obtained by means of nozzles of different diameters each having an impact tube permanently attached to it. The dead weight and frictional resistance of the wires without a scoop in place (the hole covered by shellacked paper) was determined for different velocities before the scoops were inserted. Thus, with the air velocity past the plate and scoop known, and the weight passing through the scoop or sea chest determined by the nozzle, the theoretical drag could be calculated, and the factor f is then

$$f = \frac{\text{actual drag}}{\text{theoretical drag}}$$

The writer did not test a common type of sea chest, but it may quite safely be assumed that its " f" would not be less than for divergent scoops operating below their " normal" capacity, under which conditions the " f" is larger than for " normal" capacity, in spite of the smooth stream lines into the inlet of a divergent scoop.

The usual sea chest is always of such large inlet area that the flow past it must be very much disturbed and hence its " f" higher than for a divergent scoop at " normal" capacity. The factors in the normal operating ranges of scoops are:

$f = 1.5$ for divergent scoops

$f = 2.5$ for common or parallel-tube scoops

A rather surprising result of these tests was the fact that when a divergent scoop is operating above normal capacity, that is, when there is actually a suction at its inlet, the resistance increases very rapidly, whereas it would be thought that the suction which acts at a small angle to the plate would materially reduce the drag, which shows that nature does not permit us to get anything for nothing.

Now, if we substitute the values of f in the theoretical formula, we get

$$\text{S. H. P.} = \frac{QV^2}{57{,}500\ E_p} \quad \text{for divergent scoops and sea chests.}$$

$$\text{S. H. P.} = \frac{QV^2}{34{,}500\ E_p} \quad \text{for common scoops (parallel tube)}$$

If we take the case of a destroyer of 80,000 S.H.P. at 42 k and assume the circulating water at 80,000 gallons per minute (one gallon per minute per S.H.P. is a fairly accurate rule), the power put into the circulating water is

$$\text{S. H. P.} = \frac{80{,}000 \times (42)^2}{34{,}500 \times .53} = 7700$$ for common scoops and 53 per cent propulsive efficiency.

The percentage of power loss is

$$\frac{7700}{80{,}000} \times 100 = 9.6,$$ or, if divergent scoops are used

$$\text{S. H. P.} = \frac{80{,}000\ (42)^2}{57,\ 500 \times .53} = 4600$$ or 5.8 per cent.

The total loss due to circulating water must really be greater than calculated since this includes only the inlet loss, whereas there is a considerable further added resistance due to the disturbance of the stream lines around the overboard discharge. The writer has not yet made any determinations of this loss, which must be done before we have the complete story.

While it may be argued that there are so many uncertainties still remaining in going from model to ship that a matter of a few per cent need not be taken into consideration, it seems that where an element entering into the resistance can be calculated with certainty, it should be taken into account. Possibly if it were, it might, in a measure, help to clear up some of the differences existing and lead to some minor corrections to other of the factors.

From the foregoing, the reader has possibly arrived at the conclusion that scoops are an expensive way to get circulating water and that it would be more economical to use pumps. This is not a fact, however, since the S.H.P. required to accelerate the circulating water to the ship's speed is the same whether a scoop is employed or an ordinary sea chest where the water is taken in at right angles to the hull.

The use of scoops for high-speed ships is an economic necessity, since in the case of scoops the water is circulated through the condenser without the expenditure of further power, whereas, if pumps are employed, in addition to the power put into acceleration

of the water, steam is required to drive the pump. In the case of the destroyer cited as an example, the turbines or motors required to drive the pumps would have to develop about 650 B.H.P. if the scoop effect were not utilized.

The combination of scoops with a pump and the use of two-pass condensers might work out slightly more efficiently from the standpoint of steam consumption, but the simplicity and reliability of the scoop system would be lost. This is not justified in naval vessels, as the condenser would be heavier, and it means more moving machinery in operation and more chance of casualties.

There is one phase of propeller design for high-speed naval vessels which seems to have been overlooked, due, no doubt, to the fact that the naval architect who generally designs propellers is not a turbine engineer, and consequently, does not consider the combination of turbine and propeller.

Diagrammatically, in Figure 2 is shown a speed–R.P.M. curve typical of the usual cruiser or destroyer propellers. Also by the dotted line is shown the speed–R.P.M. curve, which may be obtained by the use of a larger projected area ratio, assuming that we are not in the region, or are beyond the region of the major "hump" in the resistance curve. Actually, of course, both these lines will have certain waves in them corresponding to the variations of hull resistance at different speed-length ratios.

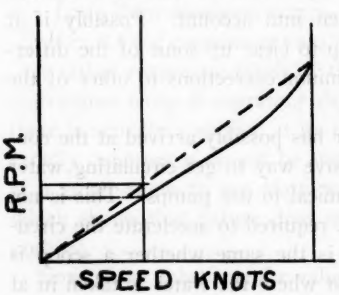


FIGURE 2.

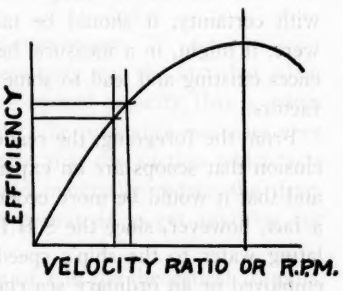


FIGURE 3.

Diagrammatically, a type efficiency curve of a steam turbine is shown in Figure 3 plotted against velocity ratio or R.P.M. This curve is very nearly a parabola for all types of turbines.

In designing a marine turbine for high-speed vessels, limitation of weight, space, critical speeds and strength of turbine rotor materials, restrict the turbine designer to a velocity ratio not much over that corresponding to the maximum efficiency at the maximum speed, though he may, as the writer has done, go slightly beyond the maximum point, in the high-pressure turbine, at full speed in order to come up higher on the efficiency curve at cruising speeds.

Now, if in both Figures 2 and 3, we assume the cruising speed to be at one-third full speed, it is seen that on the turbine efficiency curve, the efficiency increases very rapidly in the lower part of the curve and is nearly directly proportional to the speed, as the curve is here almost a straight line.

Referring now to Figure 2, at approximately one-third full speed, it is obvious that the propeller revolutions at cruising speed would be a considerable percentage higher for a propeller which more nearly gives the dotted speed–R.P.M. line than for one giving the normal heavy curve.

This same proportion of increased R.P.M. or velocity ratio of the driving turbine would give nearly the same proportionate increase in turbine efficiency.

It would seem, therefore, that even though it is necessary to sacrifice two or even three per cent in propeller efficiency at cruising speed, there would still be a very considerable gain in overall economy at cruising speeds, due to the turbine gain being greater than the propeller loss. In doing this, however, we also reduce the maximum power required to drive the ship, since, in increasing the projected area ratio to avoid cavitation, we also increase the propeller efficiency at full speed.

As far as the writer could discover by personal contact with designers and by reference to literature on the subject, it has been the thought generally to keep the projected area as small as possible, even deliberately permitting a small amount of cavitation at the highest speeds in order to get a higher propeller efficiency at cruising speeds.

For the reasons previously outlined, the writer believes the reverse is true.

DISCUSSION OF NOTES ON E. H. P. CALCULATIONS.

By Lieutenant H. A. Schade (C.C.), U. S. Navy.*

The method proposed by Mr. Schmidt for evaluating the increase in the ship's resistance, or in the S.H.P., resulting from the action of the condenser scoops, possesses the virtue of novelty, and gives results which are rather startling. To find it stated and proven by this method that in a destroyer at 42 knots speed a common scoop will absorb 7700 S.H.P., or 9.6 per cent of the power, is enough to immediately stir the reader's interest. A closer examination of the facts, however, indicates that such estimates are probably considerably in excess of the actual values.

The difficulty in way of making model tests to determine the effect of scoops is not great. While it is true that model frictional resistance is relatively a greater proportion of the whole in the model than in the full-sized ship, the methods of evaluating the frictional resistance are quite well established and model results can be translated to the full sized ship within limits of accuracy much smaller than the 9.6 per cent error which the author calculates results from the presence of the common type of scoop. The Washington Model Basin has conducted model tests with simulated scoops to determine the increase in resistance resulting from them, with results which indicate that the scoop resistance is very small.

There are several facts which must modify the theoretical conception of the mass of circulating water with kinetic energy imparted to it by the ship on the basis that the water acquires the velocity of the ship in the forward direction. In the first place, the circulating water is taken, not from water at rest, but from the boundary layer, that is, the mass of water which is moving along with the ship at some fraction of the ship's velocity. Secondly, the circulating water cannot acquire the full velocity of the ship, otherwise there would be no motion of the water relative to the ship and

* Design and Construction Division, Bureau of Construction and Repair.

no circulating water would flow. And third, some of the kinetic energy acquired by the water must be returned to the ship due to the fore-and-aft component of the discharge velocity.

The effect of scoops and the condenser cooling system may best be regarded as augmented resistance to the two components of the ship's resistance, that is, frictional and residuary (eddy-making and wave-making) resistance. From this standpoint, the inside surfaces of the seachests, tubes, etc., simply create additional frictional and residuary resistance as the water passes through them.

Such arguments are, of course, highly theoretical. The soundest basis on which to judge the merit of the evaluation of scoop resistance as proposed by the author lies in the proven fact that model basin predictions of resistance and power are made with reasonable accuracy without taking account of the scoop resistance in the manner proposed.

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Machinery, November, 1933.

THE STELLA DUAL MAGNETIC COMPASS.

Engineering, October 27, 1933.

AERONAUTICAL RESEARCH.

The Engineer, September 1, 1933.

NAVAL TRAINING—A GENERAL REVIEW.

Journal Royal United Service Institution, August, 1933.

THE ELECTRO-CHEMICAL THEORY OF CORROSION.*

By Oliver P. Watts.†

It has been said of electrolysis that it splits a chemical reaction in two and permits the halves of the reaction to occur at different places. The beauty of this characterization can be appreciated only by those who are conversant with both electrolysis and corrosion. In ordinary cases of corrosion, such as the attack of zinc or iron by sulphuric acid, the two halves of an electrolytic reaction have been put together again, and the same piece of metal serves as anode and as cathode. The most fundamental law of electrolysis still applies, viz., Faraday's law, that the total of chemical changes at the anode, where metal tends to enter solution, equals the total changes at the cathode, where elements leave the solution. The amount of hydrogen displaced from sulphuric acid by zinc is equivalent to the quantity of metal dissolved. This seems to indicate that the nature of the processes by which metal passes into solution by chemical and by electrolytic corrosion is the same.

According to the old view, attack on a metal like iron by an acid such as hydrochloric is strictly a chemical process, the greater affinity of the iron for chlorine enabling this metal to rob the acid of its chlorine, thus displacing the hydrogen.

Today the majority of students of corrosion, and probably of chemistry also, appear to have accepted Nernst's view, that the dissolving of metals by acids or other corroding media takes place by ions (electrically charged atoms) leaving the surface of the metal. All that is needed for atoms of a metal to go into solution is that they be provided with tickets of admission, a number of positive charges equal to the valence of the metal in that particular solution. The former importance of the anion has vanished. Now it serves only for carrying current through the solution, and of itself contributes in no way to the dissolving of metal. The army of anions on reaching a soluble anode merely come to rest there and permit the metallic ions leaving the anode to pass peaceably through their ranks.

CORROSION CLASSIFIED.

Except for a single type, not often encountered, all corrosion of metals is by displacement. For simplicity and convenience, corrosion may be classified as follows:—

(I) *Corrosion without displacement of anything from the corroding solution, e.g.,* the dissolving of iron or copper by a solution of ferric chloride.

II. *Corrosion by displacement of a metal, e.g.,* the dissolving of iron by a solution of copper sulphate or of zinc in the recovery of gold from cyanide solutions.

III. *Corrosion by visible displacement of hydrogen, e.g.,* the dissolving of zinc by sulphuric acid.

IV. *Corrosion by invisible displacement of hydrogen,* following by its physical or chemical removal, *e.g.,* the corrosion of iron by sea water or of copper by dilute sulphuric acid. This is often called corrosion by oxygen depolarization.

Type I.—This kind of corrosion occurs only when there is in the corroding solution in one of its higher valences a metal which is capable of existing in solution in at least two valences. Corrosion of this type is seldom met com-

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mercially, but is made use of in etching metallographic specimens with ferric chloride. Metal dissolves with equivalent lowering of the valence of the metal previously in the solution.

Type II.—In arranging electro-chemical series of the metals, this type of corrosion was extensively studied in the early part of the nineteenth century, although attention was then focussed on the deposition of the one, rather than on the corrosion of the other of the two metals concerned in each case. The serious consequences of confining in a tank or pipe made of an active metal a solution containing a much more inert metal, is so well known that this type of corrosion is rarely encountered. One metal replaces the other in solution. Short of actual trial, tables of potentials and of solubilities furnish the best basis for prediction in regard to this type of corrosion.

Type III.—Corrosion by visible displacement of hydrogen is possible only in those electrolytes from which the electric current deposits hydrogen, *i.e.*, water, and solutions of acids, alkalies and salts of sodium, potassium, aluminium, &c. Visible displacement of hydrogen occurs when the potential of the metal exceeds the discharge potential of hydrogen on that metal from that particular solution.

Type IV.—Corrosion by invisible displacement of hydrogen is by far the most common type of corrosion, yet is least understood. This occurs only with those metals and in those solutions in which the discharge potential of hydrogen exceeds the potential of the metal. Corrosion by invisible displacement of hydrogen proceeds as follows: When the metal is immersed in the solution it begins to dissolve, displacing its equivalent in hydrogen. This continues until the counter e.m.f. set up by hydrogen equals the thrust of the metal to go into solution, when dissolving of metal and displacement of hydrogen cease. In the case of metals whose potentials lie far below the discharge potential of hydrogen on them, the contact surfaces of metal and electrolyte must be far from saturated with hydrogen.

Oxygen from the air dissolved in the electrolyte removes hydrogen by formation of water, thus lessening the force with prevented further displacement of hydrogen, so that dissolving of metal begins again. The speed of solution of metal is limited to the rate at which oxygen reaches its surface.

PURITY *versus* CORROSION.

Will a perfectly pure metal corrode? This question has often been argued *pro* and *con*, usually with the result of leaving each of the disputants "of the same opinion still." Several authorities on corrosion disagree on this seemingly simple question, which, nevertheless, involves the fundamental principles of corrosion.

The whole argument for cessation of the corrosion of metals, if they could be obtained perfectly pure, is based on the stopping of visible displacement of hydrogen by amalgamated zinc and by certain samples of this metal of exceptional purity. No thought seems to have been given to the fact that corrosion by oxygen depolarization still goes on—that variety of corrosion which is responsible for the major part of the annual damage by corrosion.

Advocates of the necessity for voltaic couples, points of different potential, as an antecedent to corrosion, apparently limit this claim to cases where anode and cathode consist of the same piece of metal. No one has yet claimed that there must be impurities in a metallic cathode in order that hydrogen may be displaced on it by electrolysis.

Should further experiments prove definitely that no perfectly pure metal is capable of visibly displacing hydrogen on itself from acids, which seems utterly incredible in the case of sodium, potassium, calcium, &c., nitric acid would still continue to dissolve absolutely pure zinc and copper, and corrosion

of these metals in sulphuric acid by oxygen depolarization would go on, as would corrosion by displacement of other metals and by the method of Type I of the author's classification. Metallurgists need not worry about zinc being made so pure that it will fail to precipitate gold from cyanide solution and sacrifice itself in doing so.

THE ROLE OF OXYGEN AND OXIDIZING AGENTS IN CORROSION.

It is observed that oxygen and oxidizing agents stimulate corrosion of metals. Early in the history of the voltaic cell it was discovered that unless an oxidizing agent was placed at the cathode, the current delivered by the cell quickly diminished through polarization by hydrogen—*i.e.*, deposition of hydrogen on the cathode caused its potential to approach that of the zinc, thus lowering the e.m.f. of the cell. With few exceptions, the electrolytes of voltaic cells are those from which hydrogen is deposited at metallic cathodes when electrolysis occurs. To prevent this serious fall in e.m.f. during use, oxidizing agents are placed at the cathode either as a constituent of electrode or electrolyte. Studies of the Leclanché cell have shown that reduction of the manganese dioxide accounts for removal of only half the hydrogen deposited at the cathode. The remainder is removed by oxygen from the air dissolved in the electrolyte. In Vol. 62 of the "Transactions" of this Society a commercial air-depolarized cell is described. Polarization at the cathodes of primary cells has long been known, understood, and the removal of the polarizing hydrogen provided for by oxidizing agents, and finally by atmospheric oxygen.

About eighty years' study and experimenting in corrosion was required before this was recognized as electro-chemical in character, and the function of oxygen in stimulating corrosion was not made clear for several years more. In any aqueous solution from which hydrogen is deposited on metallic cathodes, its deposition tends to displace the potential of the metal toward that of zinc. It is not necessary that there be enough hydrogen on the metal for visibility in order to cause this change in potential. It begins as soon as any e.m.f. is applied to the cell, and if the e.m.f. is gradually increased it continues until both electrode and electrolyte at the metal-electrolyte interface are saturated with hydrogen and the gas begins to escape.

When a metal is placed in a solution of sulphuric acid or sodium chloride, it begins to dissolve by the only process possible, by displacing some other element from the solution. In acids and solutions of sodium and potassium salts the substance displaced is hydrogen, the element which is deposited at cathodes from these solutions by electrolysis. In a voltaic cell without a depolarizer, *e.g.*, amalgamated, zinc-sulphuric acid-copper, hydrogen is visibly evolved from the copper, and no one can doubt its displacement by the dissolving of the zinc. When copper is placed in dilute sulphuric acid, it, too, starts to dissolve by displacing hydrogen, but the discharge potential of hydrogen on copper from dilute sulphuric acid exceeds the potential of copper in the same electrolyte; hence copper can continue dissolving only until hydrogen has accumulated on the metal to a concentration equivalent to the potential of copper; then there is equilibrium, and no more copper can dissolve until some of the hydrogen is removed, thereby lowering the opposition to its deposition. If air has access to the electrolyte, the oxygen slowly removes hydrogen and permits copper to dissolve at the exact rate necessary to replace the hydrogen as fast as it is removed. In the complete absence of oxygen copper does not corrode perceptibly in dilute sulphuric acid in years.

In April, 1926, the writer sealed in glass tubes in normal sulphuric acid inch-long (2.54 centimeters) pieces of bright copper wire. The acid was boiled in the tube under diminished pressure and sealed under vacuum. One

tube was left unsealed. The wire and liquid in this have completely disappeared, and in their place is dry copper sulphate. The acid in one tube became faintly blue after a month. Careful scrutiny showed a minute crack in the glass where sealed. Although the liquid has not evaporated enough air has diffused through the crack to cause serious corrosion of the copper. In two other tubes the acid is still water-white, and the copper is as polished as when put into the tube seven years ago.

Not only does a zinc anode displace hydrogen on the cathode of a voltaic cell when they are connected, but it displaces hydrogen on itself. In neutral electrolytes, from which the discharge potential of hydrogen on zinc and its impurities exceeds the potential of that metal, no hydrogen is seen; but in acids where the discharge potential of hydrogen is much lower, it is necessary to amalgamate the zinc to prevent continuous evolution of hydrogen on the anode and corresponding waste of zinc. Although there is now no evolution of hydrogen on open circuit, corrosion by oxygen depolarization goes on. This corrosion of amalgamated zinc by depolarization of the invisible film of hydrogen always present on it was recognized years ago, and the zincs were removed from the single-fluid bichromate cell when not in use, to prevent waste through oxidation of the hydrogen film by the chromic acid.

CORROSION BY DIFFERENTIAL AERATION.

Corrosion by differential aeration has been much discussed. When two separate pieces of iron are placed in a neutral electrolyte and oxygen maintained at a higher concentration at one piece than at the other, the iron with the higher oxygen concentration corrodes faster and its potential is lower (more noble) than that of the other piece. When the electrodes are connected, each piece is privileged to displace hydrogen on the other as well as on itself. Enough current now flows from the metal where hydrogen is the more concentrated to raise the polarization by hydrogen of the other electrode until their potentials are equal, except for the e.m.f. required to drive the current through the cell. The corrosion of the two electrodes should differ by an amount equivalent to the current.

Two explanations are suggested for corrosion by differential aeration. The first is that an oxide film is formed on the metal having the higher concentration of oxygen. "It is clear, therefore, that the formation of protective films on the aerated part of the metal does play a very considerable part in causing the aerated area to be cathodic."*

"The portions to which oxygen has least ready access are those where corrosion is greatest. This conclusion may at first sight seem almost paradoxical, but the action of oxygen is of the direct chemical type, giving at the aerated portions a uniform film having some protective qualities. These parts are thus ennobled and the parts sheltered from oxygen are relatively electronegative (more active) and dissolve by anodic attack of the ions in solution."†

The other explanation is that this is merely a case of ordinary corrosion by oxygen depolarization, except that the two portions of the same metal which act as anode and cathode happen to be connected by wires instead of being a single piece of metal. The initial differences in potential are characteristic of metals when the hydrogen concentration at the metal-electrolyte surface is changed.

It is generally considered that the velocity of corrosion by oxygen depolarization is controlled by the rate of diffusion of dissolved oxygen to the metal. This means that when the oxygen arrives at the metal surface hydrogen is

* Evans' "Corrosion of Metals," p. 93.
† Hedges' "Protective Films on Metals," p. 47.

already there, and the oxygen has a choice of uniting with hydrogen or metal. That an oxide should be formed in the presence of hydrogen, and later be reduced by hydrogen, seems an entirely unjustifiable, not to say unreasonable, assumption. Granting that an oxide is formed, it should, like the copper oxide cathode of the Edison primary cell, prevent accumulation of hydrogen, and so promote continued flow of current. Dr. Blum makes the revolutionary suggestion that no hydrogen is displaced by metals dissolving by oxygen depolarization, but that "cathodic reduction of oxygen can be considered an electron reaction, which is much more likely to occur than the frequently assumed process of hydrogen evolution and subsequent reduction of oxygen by hydrogen."

ELECTROLYTIC PROTECTION.

In electrolytic protection the metal is made cathode and loaded up with hydrogen by an external e.m.f., so that there shall be no point on which the metal can itself push out hydrogen. In the Gunderson process plating with arsenic insures that there shall be no corrosion of the steel by visible displacement of hydrogen, for the discharge potential of hydrogen on arsenic, even from acids, exceeds the potential of iron.

RESIDUAL CURRENT AND CORROSION.

Residual current is that microscopic current which flows in an electrolytic cell at any voltage below the e.m.f. of decomposition without visible products of electrolysis. It is the current equivalent of the rate of depolarization of the electrodes by the electrolyte. At a constant voltage the current diminishes with time, but never ceases. It has been studied both with platinum electrodes and an e.m.f. external to the cell, and with electrodes of different metals, in which case the cell supplies its own e.m.f.

Corrosion of type IV is the same phenomenon, except that here a single piece of metal serves both as anode and cathode; but the corrosion is controlled by the rate of removal of hydrogen by dissolved oxygen, just as both current and corrosion in the experiment cited are fixed by the rate of depolarization of the cathode. A thorough study of residual currents under various conditions should throw much light on corrosion of type IV.

A FILM OF HYDROGEN.

Metals, when placed in acids or solutions of sodium salts, must displace on themselves a concentration of hydrogen equal to their own potentials, else there would be no acceleration of corrosion by oxygen depolarization. Copper, silver and other inert metals which are incapable of visibly displacing hydrogen from dilute sulphuric acid, corrode very slowly when allowed to stand in the acid.

It is only at the potential of copper in sulphuric acid, for example, that there can be equilibrium between copper and hydrogen; at any potential more noble than this, if copper began to deposit on a cathode, it must re-dissolve with displacement of hydrogen until equilibrium is reached. So very minute currents of the order of magnitude of residual currents deposit hydrogen, not copper, from air-saturated solutions of copper sulphate.

In the early days of the study of corrosion the mistake was made of attributing the stopping of corrosion by the film of hydrogen to its insulating power, and in some quarters this erroneous opinion is still held. It is the polarization (counter e.m.f.) produced by it, not its resistance, that reduces corrosion and the current in voltaic cells. In one case the residual current

between nickel and iron was found to be 1/20,000 of the current density usually used in chromium plating, where a storm of hydrogen is evolved at 6 to 8 volts. The resistance of the films of hydrogen encountered in corrosion are negligible.

NERNST'S OSMOTIC PRESSURE AND HELMHOLTZ'S ELECTROLYTIC DOUBLE LAYER.

"According to the well-known classical theory of Nernst, each metal has a definite solution pressure, which is a measure of the tendency of the metal to pass into aqueous solution in the form of ions. This solution pressure is opposed by the osmotic pressure of the metal ions, which tends to drive them out of solution, depositing them on the metal. With the reactive metals, such as zinc, the solution pressure is greater than the osmotic pressure, positively charged zinc ions go into solution, and the metal acquires a negative charge. When the solution pressure is less than the osmotic pressure, as in the case of copper and the 'nobler' metals in solutions of their salts, ions of the metal are deposited, giving a positive charge to the electrode, while the solution in the vicinity is negatively charged by the corresponding anions. The surface of the electrode is thus the seat of an electric double layer."*

The solution pressure of zinc is stated to be 9.9×10^{18} atmospheres, or five million billion tons per square inch, and that of copper 4.8×10^{-20}, a quantity unimaginably small.

"In accordance with Nernst's assumption, when a bar of zinc is placed in water, zinc atoms each give up two electrons to the bar of metal and pass into the water as positively charged ions. In this way an electric double layer is formed at the junction of the metal and liquid. That but an exceedingly minute quantity of zinc enters the water in the form of ions, notwithstanding its enormous electrolytic solution pressure, is due to the electrostatic attraction of the negative charges which accumulate on the bar of metal. Evidently the relative values of the osmotic pressure and the electrolytic pressure determines whether ions leave or enter solution."†

Helmholtz's double layer is a myth. Not only is it stated above that metal ions pass into solution without displacing their equivalent in other positively charged ions, but the very existence of a double layer depends on their doing so. If metals dissolve by displacing on themselves, or another conductor in electrical contact with them, their equivalent in positively charged ions, there can be no accumulation of electric charges on either metal or electrolyte! Experience shows that, except for type I, all corrosion of metals is by displacement.

Nernst's conception of the "osmotic pressure" of the ions of the metal already in solution as equalizing or even overcoming solution pressure, chemical affinity, or whatever name is applied to the force which causes metals to dissolve, is also untrue. A sheet of copper, 48 square centimeters in area, immersed for twelve days in 250 cubic centimeters of normal copper sulphate lost 0.1386 grains in weight! According to Nernst, as quoted above, copper tends to deposit from solutions of its salts.

How can osmotic pressure and an electrolytic double layer be reconciled with this corrosion of copper in a strong solution of copper sulphate by oxygen depolarization? Yet modern texts on physical and electro-chemistry continue to present Nernst's theory of osmotic pressure and Helmholtz's double layer as "law and gospel," to be swallowed by embryo scientists,

* Hedges' "Protective Films on Metals," p. 12 (1932).
† Creighton and Fink's "Electrochemistry," 1, p. 172 (1924).

greatly to the impairment of their scientific digestions! These figments of the imagination were created to explain the practical stopping of corrosion of the anode in certain primary cells when the circuit is opened, and the fact that metals of high potential fail to dissolve quickly and completely when placed in neutral electrolytes. Now that it is known that their supposed job of limiting corrosion is performed by hydrogen, and that they were never capable of doing it in the first place, they should be plainly labelled as scientific conceptions that have outlived their usefulness.

After thirty years, Whitney's statement that corrosion is electro-chemical in nature still stands as our best definition of the electro-chemical theory of corrosion.—"The Engineer," Sept. 15, 1933.

DO YOU DESIGN OR JUST "MAKE" YOUR WELDED JOINTS?

Correct Design of the Weld Itself Is Essential for Economy, Strong Construction and Subsequent Operating Safety.

By R. Kraus, Welding Engineer, Wm. B. Scaife & Sons Co., Oakmont, Pa.

Engineers interested in the possibilities of welding face quite a task in seeking basic information to be used as a guide in weld design. Books giving general information on welding are available and the published results of a great deal of research and descriptions of structures successfully built are invaluable. However, very little has been published that can be readily applied to the actual design of the weld itself. This essential phase of the process, which involves the selection of the right type and size of weld to resist satisfactorily the stresses imposed upon the joint, will be dealt with in this article. The permissible stresses recommended here are intended for weld metal deposited by means of the electric process.

TYPES OF WELDS GENERALLY USED.

Fillet and butt welds are used in the design of most joints. At A, B, and C in Figure 1 are shown both forms. Two fillet welds are indicated at A. They are triangular in cross-section, the throat lying in a plane disposed approximately 45 degrees with respect to the surfaces joined. In the single-welded butt joint shown at B, the joint is formed by the fusion of two abutting plate ends with the filler metal added from one side of the joint. Although it is not indicated, the side to which the filler metal is added is then reinforced by additional metal. The double-welded butt joint at C is formed by the fusion of two abutting ends, the filler metal being added from both sides of the joint and reinforced (not shown) on both sides.

ELIMINATING PREPARATORY FITTING TO REDUCE MANUFACTURING COST.

Welding is primarily done to reduce manufacturing cost. Preparation prior to welding, consisting of cutting, beveling, and fitting of the parts, represents a large share of the final cost. In general, a fillet weld costs less and is most desirable, as it requires little preparation in the joint itself. The fitting of this joint is also much easier when a reasonable allowance is made for unavoidable variations in manufacturing.

Proper allowances should be made to support the weld. For example, at E is shown the foot of a pedestal. From ¼ to ½ inch should be allowed from the edge, in addition to the space occupied by the weld, depending on

the size of the structure; otherwise, time will be wasted in fitting. Insufficient allowance will also result in part or all of the fillet being made under size, because if it is attempted to make the fillet full size, the liquid metal will run over the edge, and after it solidifies it will present a poor appearance, as shown at F. At D is shown how a pad can be attached to the side of a bedplate with either a fillet or a bevel weld. Note that the beveling is done on the lighter member to obviate unnecessary handling of the heavier part.

Fitting of small parts adds a good deal to the cost of fabrication. The diagram at J shows how three small pads were replaced by one larger pad. This change facilitated the fitting and reduced the amount of welding.

Another instance of simplified practice in fitting occurs in the making of tanks or similar parts having a flange. No matter how carefully the parts are rolled, the top of the vessel will not be perfectly round. This is due to a slight difference in ductility in different parts of the plates, resulting in uneven stretching. With the weld design indicated at G, fitting is easy. The fillets between the two component parts can be made with no difficulty. However, if the design of weld indicated at H is used, difficulties will be experienced in welding, due to the unavoidable gaps between the two mating parts.

INACCESSIBLE WELDING SHOULD BE AVOIDED.

Easy access for welding will help to keep the cost down and the welds will be more likely to be of better quality and capable of developing full strength. The frame at K can be readily welded, as the welds are accessible. If many of these frames are to be made and a jig is provided, the welding can be finished at one set-up. If the frame were fabricated as shown at L, the right-hand welds would be inaccessible. To make the lower welds, it would be necessary to turn the frame over and probably remove it from the jig.

It might be well to point out here how to recognize an inaccessible weld on a drawing. If the throat line is extended and bisects any adjacent part, it is evident that the electrode cannot be pointed correctly at the fillet. Pointing the electrode in any other way than in the direction of the throat line does not permit the arc to be played equally on the vertical and horizontal surfaces between which the joint is made.

Another example of an inaccessible weld is that of a pipe connection to the inside of a tank. Occasionally, as in vacuum-tight work, a weld of this type is necessary. For example, at M the lower part of the weld cannot be made at all, while if the weld is made as shown at N, it is possible to weld around the entire periphery of the pipe.

HOW SUBSEQUENT PRESSURE TESTS INFLUENCE THE DESIGN OF THE WELD.

Subsequent pressure tests influence weld design. Assuming that the vessel indicated at O has to be oil-tight, any leaks in the outside weld can be observed easily during the test. If an inside weld is necessary for strength, it should be intermittent. This is important, because if both welds are continuous, it may take longer for the testing oil to seep through to the outer weld than the time allowed for the test. Hence, defects in the outer weld will not be detected until the vessel is put into use.

A design is unsatisfactory if it cannot be conveniently observed during the test of the weld, which is the case with the tank shown at P. A special fixture is necessary for mounting this tank and the observer must of necessity be under the tank. In addition, if such a tank leaks after being installed, difficulties will be experienced in making repairs.

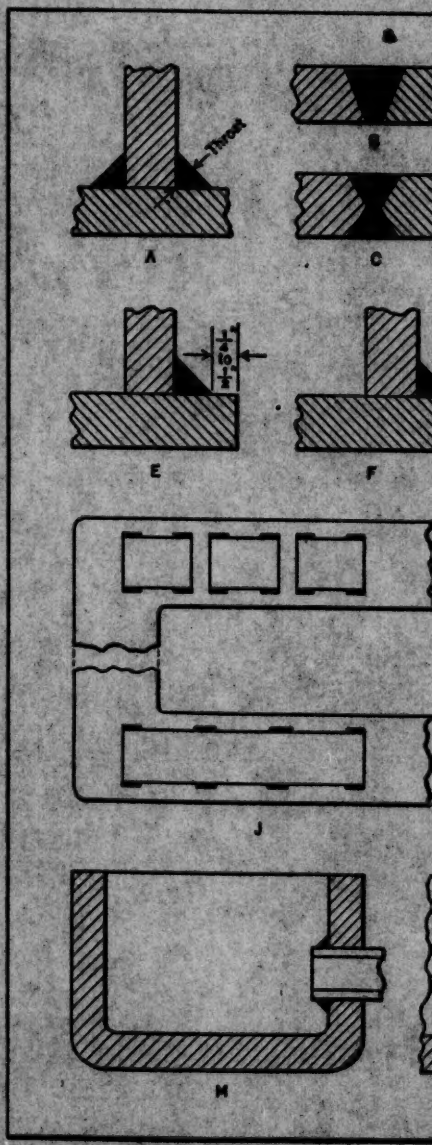
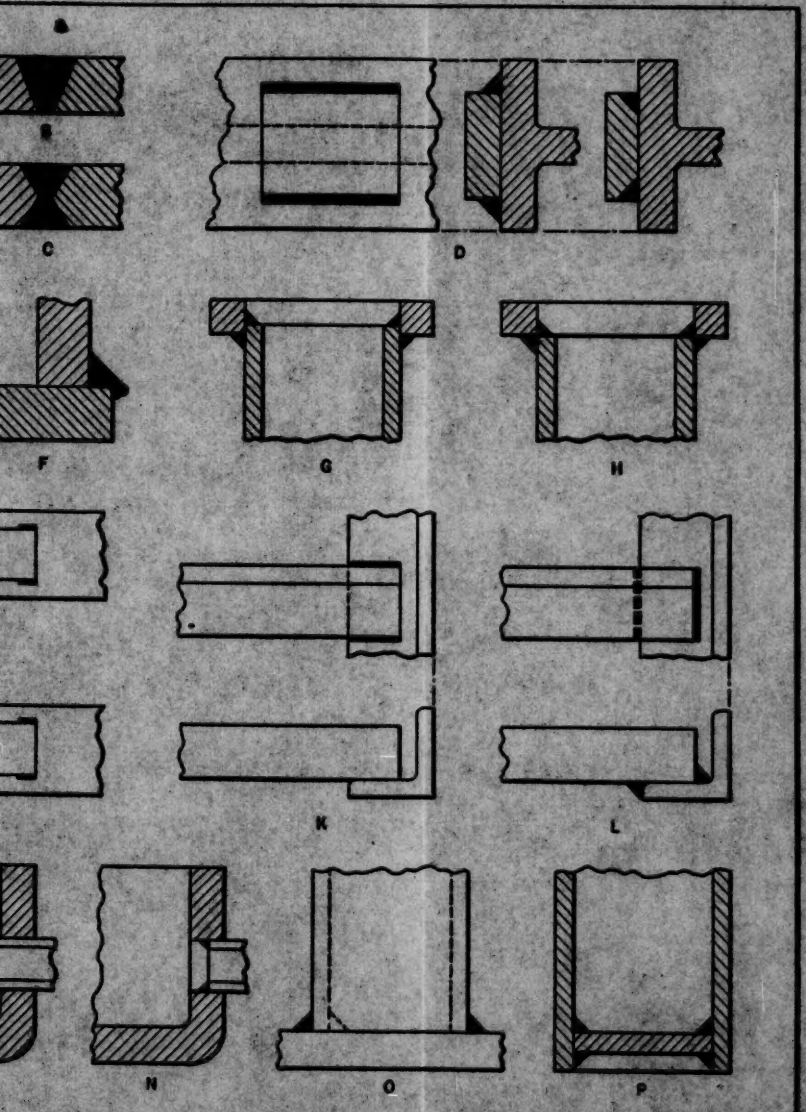


FIG. 1.—DIFFERENT APPLICATIONS OF WELDED J



F Welded Joints, Some of Which Are Open to Criticism, as Explained in the Text.

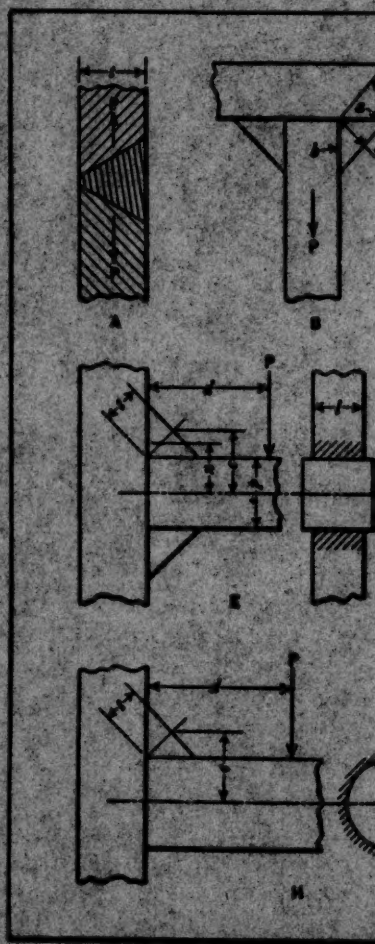
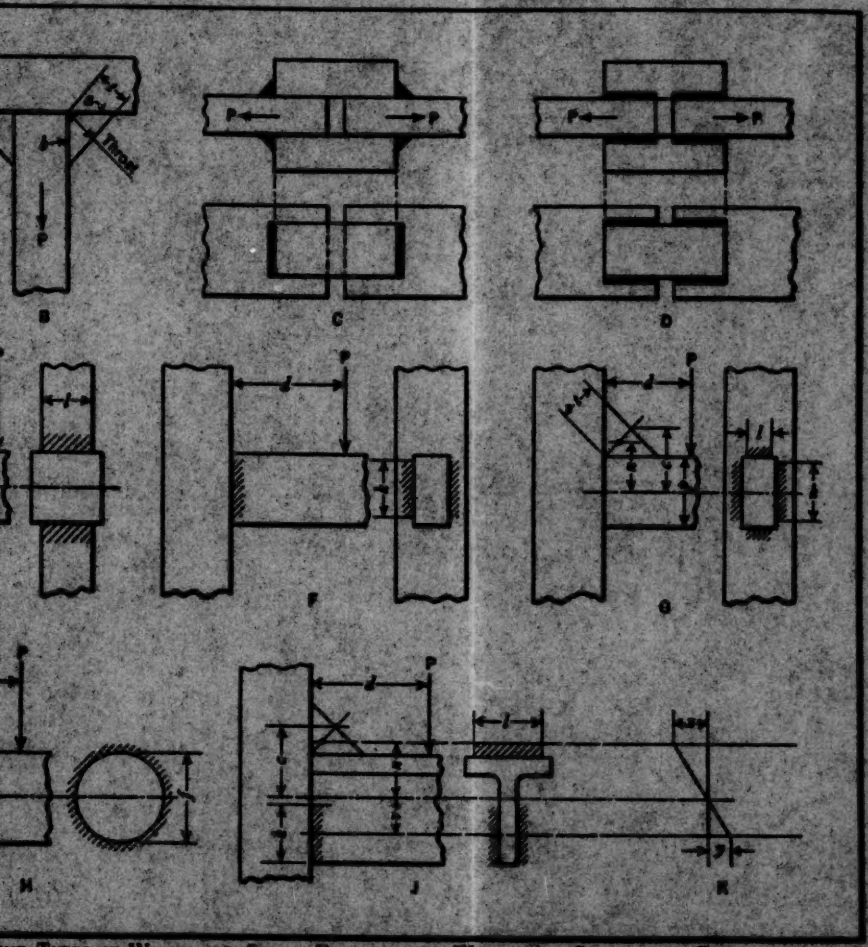


FIG. 2.—DIFFERENT TYPES



EIGHT TYPES OF WELDS, THE STRESS FORMULAS FOR WHICH ARE GIVEN IN THE TEXT.

PREPARING THE JOINT FOR BUTT-WELDING.

In selecting the form of the joint and the preparation required, the designer must keep clearly in mind the fact that the final cost depends on the amount of preparation and the quantity of filler metal necessary. Incidentally, contraction stresses and warping are proportional to the amount of filler metal used. The only reason parent material is removed prior to welding is to make the component parts accessible.

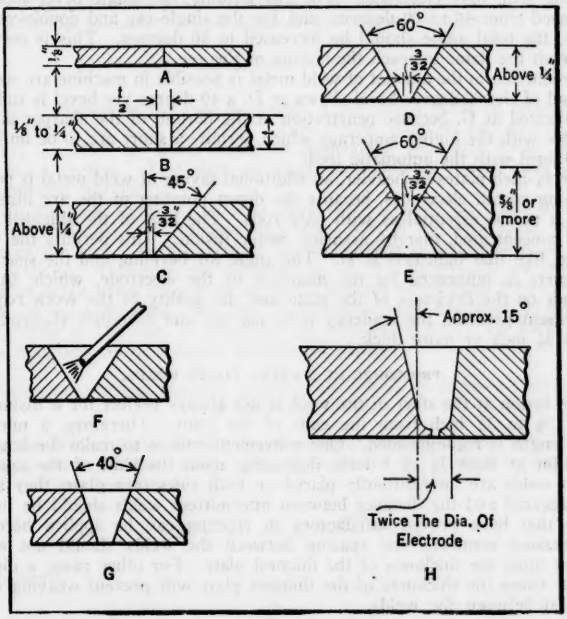


FIG. 2.—RECOMMENDED DESIGN OF VARIOUS BUTT JOINTS FOR DIFFERENT PLATE THICKNESSES.

The type of joint is influenced by the thickness of the plate, the method of welding—if done manually or by automatics—and by the type of electrode that is used. Working with bare electrodes requires better access of the arc to the abutting edges of the plates. To be sure of fusion when using bare electrodes, it is necessary to point the arc approximately at right angles to the beveled side of one part and still have clearance between the electrode and the side of the other part, as shown diagrammatically at F, Figure 2.

The preparation of butt joints for various thicknesses of plates is shown in Figure 2. Butt welds require no preparation when the component parts are less than ¼ inch thick; and, as indicated at A, for welds up to ⅛ inch thick, the parts may be butted with no gap. In the latter case, the heat of the arc or torch penetrates the full thickness of the plate. Above ⅛ inch

and up to ¼ inch, as shown at B, a gap should be provided between the component parts equal to about one-half the thickness of the plate. With plates greater than ¼ inch thick, at least one of the plates should be beveled, as at C. However, if the full strength of the plates is to be developed, both plates should be beveled, as at D.

Plates ⅝ inch thick or more are generally prepared, as indicated at E, for a double-vee butt weld, if both sides are accessible for welding. The angles for beveling shown at C, D, and E are intended for manual arc welding with bare electrodes. For gas welding, the single bevel should be increased from 45 to 60 degrees, and for the single-vee and double-vee butt welds, the total angle should be increased to 90 degrees. This is necessary to permit the flame to reach the bottom of the vee.

A reduction in the amount of weld metal is possible in machine arc welding. Instead of the 60-degree bevel shown at D, a 40-degree vee bevel is sufficient, as indicated at G, because penetration at the bottom of the sharper angle is possible with the higher amperage which permits a short arc to be uniformly maintained with the automatic feed.

For ¾-inch plates or heavier, an additional saving of weld metal is possible by using coated electrodes, because the direct pointing of the arc illustrated at F is not so essential as with bare rods. The heat of the shielded arc is more concentrated, thereby assuring better fusion. This permits the use of a joint like that indicated at H. The angle for beveling and the spacing of the parts is influenced by the diameter of the electrode, which, in turn, depends on the thickness of the plate and the quality of the work required. In present practice, the tendency is to use ¼- and 5/16-inch electrodes for plates ¾ inch or more thick.

PROCEDURE IN MAKING FILLET WELDS.

The fusion at the start of the weld is not always perfect for a distance of about ⅛ to ¼ inch from the ends of the joint. Therefore, a minimum fillet length is recommended. One convenient rule is to make the length of the joint at least ¾ or 1 inch, depending upon the skill of the operator. When welds are intermittently placed on both sides of a plate, they should be staggered and the distance between intermittent welds should be limited. Rules that have proved satisfactory in riveting can be applied here. In compression members, the spacing between the welds should not exceed sixteen times the thickness of the thinnest plate. For other cases, a distance of fifty times the thickness of the thinnest plate will prevent weaving of the material between the welds.

CALCULATING THE STRESS THAT A BUTT-WELDED JOINT MUST RESIST.

After the form of the joint has been decided upon, it is necessary to determine the size of the joint to resist the stresses imposed upon the joint while in use. Three types of stresses are generally considered—namely, tension (or compression), shear, and bending. The simplest case of tension is that of a butt weld, as indicated at A in Figure 3. Here the stress $= \frac{P}{tl}$, P being the load in pounds and l the length of the weld. No reinforcement is shown for this butt weld. However, the Boiler Code recommends a slight reinforcement—just sufficient to avoid a depression in the finished weld. The reinforcement does not enter into the calculation and can therefore be subsequently machined off. Incidentally, a heavy reinforcement on one side establishes an eccentric loading and tends to increase the stress on the unreinforced side, and hence is objectionable.

DETERMINING THE STRESS THAT A FILLET WELD MUST STAND.

A more complicated case is the calculation of the stress affecting the fillet weld of a T-connection, such as that indicated at B. The weld joint is subjected at a to tension and at b to shear, while the minimum section, called the throat, is subjected to both stresses. Ordinarily, in order to analyze these stresses, it would be necessary to resolve them into component parts—normal and parallel to the throat section. Instead of doing this, however, it has been found more convenient to assume that the force P acts perpendicularly on the throat plane, irrespective of its actual direction, and to use arbitrarily the following simple equation for tension or shear:

$$\text{Stress} = s = \frac{P}{2tl}$$

Here, P represents the load in pounds, t the throat depth in inches, and l the length of the weld in inches. This simple equation has proved satisfactory, inasmuch as welds tested to destruction generally break through the throat section. Test data of many thousands of welds have further substantiated this fact.

With the joint shown at C, tests show better results for shear than with the joint indicated at D, because each lineal part of the weld takes an equal share of the load. In the weld at D, the loading is progressive, as in the case of rivets. However, the difference in the test figures for the two types of shear is not great enough to set up a different permissible stress for each type. When both transverse and longitudinal welds are used in the same joint, more of the load is taken by the transverse weld. In such a case, some designers allow a lower permissible stress.

FORMULAS FOR THE BENDING MOMENT FOR WELDS IN VARIOUS LOCATIONS OF THE BEAM JOINT.

The established formulas for bending apply directly to the calculation of bending stresses in butt welds. The equation for the bending moment of the weld at E can be written

$$M = Pd = 2l \times \frac{tn^2}{c} \times s$$

However,

$$n = \frac{p}{2} + \frac{1}{3}t$$

Hence,

$$M = Pd = \frac{lt}{c} \times (p + 0.67t)^2 \times s$$

When the welds are located as shown at F, the equation for the bending moment becomes:

$$M = Pd = 0.34k^2s$$

At G, both types of welds are used, in which case the formula becomes:

$$M = Pd = \frac{t}{c}\left(1(p + 0.67t)^2 + \frac{k^3}{6}\right)s$$

If round material or pipe is used, as at H, for the welded member subjected to bending, the equation will be:

$$M = Pd = \frac{\pi}{64c}\left((f + 2t)^4 - f^4\right)s$$

For the T-section shown at J, it is necessary to determine the location of the common neutral axis of the welds. This can be done either graphically or by calculation. The graphic method will be found to be the quicker. The areas of the throat planes are plotted as shown at K, y representing the area of the transverse weld and x the area of the two longitudinal welds. The equation for the bending moment will then be:

$$M = Pd = \frac{t}{c}\left(ln^2 + \frac{k^3}{6} + 2\,kv^2\right)s$$

After the permissible stresses are decided upon, the size and length of the weld can be readily determined. Weld metal desposited by the average qualified welder with bare rods has an ultimate strength ranging from 40,000 to 55,000 pounds per square inch and a ductility of 5 to 10 per cent in a 2-inch specimen. Coated rods of weld metal, however, will have an ultimate strength of from 60,000 to 75,000 pounds per square inch, and a ductility of at least 20 per cent in a 2-inch specimen.

The term "coated rod" is intended to include any type of rod with a covering that will produce a shielded arc—that is, one surrounded with an atmosphere for protecting the weld metal against oxidation. Many shops base their calculation on lower ultimate strengths, namely, from 40,000 to 60,000 pounds. In building construction, however, where bare rods are used, 45,000 pounds has been taken as standard. With suitable electrodes, proper parent material, and qualified welders, results can be anticipated within close limits; hence the quality of the weld does not depend upon the personal factor alone.

For convenience, Table 1 is shown giving the permissible stress per inch of length for the most common sizes of fillets. A safety factor of 4 is used, as is customary for static loads. These stresses can be reduced in proportion for other safety factors.

Table 1. Permissible Stresses for Fillet Welds

Throat Depth of Fillet, Inch	Ultimate Strength, Pounds per Square Inch		
	40,000	45,000	60,000
	Permissible Stress, Pounds per Inch of Length		
1/4	1770	2000	2650
3/8	2650	3000	4000
1/2	3540	4000	5300

In this table it is assumed that the permissible stresses for tension, compression, and shear are the same. This will be found acceptable for the design of machine parts in general, although the Building Code permits somewhat higher figures for tension and compression. The table is limited to ½-inch fillets. Larger welds than ½ inch are, of course, used when concentrated stresses require it.

AVOIDING THICK WELDS TO REDUCE MANUFACTURING COSTS.

In general, it is more economical to use smaller welds and make them longer. The strength of a fillet increases with its length and size, while the volume of the weld metal increases with the square of its size. For example, assume that a safe load is 30,000 pounds for 10 inches of ⅜-inch fillet or 7½ inches of ½-inch fillet. The volume of the 7½ inches of ½-inch fillet weld will exceed that of the 10 inches of ⅜-inch fillet by 33 per cent, yet the strength remains the same.

There is a practical limit to the sizes of the fillets used in the joints of component parts. For instance, a fillet that is too small, say a ¼-inch fillet on ¾-inch material, is not desirable, because its volume is insufficient and the fillet is likely to crack during cooling. That is, the heat absorbed by the component parts so far exceeds that in the fillet that the contraction of the former may set up undue stresses in the fillets during cooling which are often sufficient to cause rupture. The same judgment should be used in the choice of the fillet size as in the proportioning of machine parts.

Handling of large pieces frequently imposes greater localized stresses on the welds than the normal operation of the equipment. Hence, as a general guide, it is recommended that fillets should be no smaller than ⅜ inch in the fabrication of heavy parts, and ¼ inch on lighter pieces that are welded in a shop producing heavy work. Another argument in favor of the larger fillets is that in hand-welding with 3/16- and ¼-inch electrodes, it is difficult to make fillets smaller than ¼ inch.

Table 2 can be used in the selection of suitable fillets for joining plates of a given thickness, the thinnest plate in the assembly governing the size of the fillet.

Table 2. Fillet Sizes for Different Plate Thicknesses

Plate Thickness, Inch	Fillet Size, Inch
1/8 to 3/16 (inclusive)	1/8 to 3/16
1/4 to 3/8 (inclusive)	1/4
Above 3/8 to 5/8 (inclusive)	3/8
Above 5/8	1/2

In order that the manufacturing cost will not be increased unnecessarily, the amount of welding metal should be held to the minimum, consistent with the required strength. Although the cost of welding rod per pound is relatively small, the cost of depositing this metal is an essential item and ranges from $1 to $2 a pound. Incidentally, for lighter work, the danger of warping is increased when large amounts of metal are deposited.

In Figures 1 and 3, fillet welds have been indicated as small "blacked in" triangles in end views, and as heavy lines in other views. This method is very convenient for showing fillet welds and is suitable for most machine details. Intermittent welds can be readily dimensioned. In this way continuous welds need be indicated only in the end view, where they appear as triangles, with a note "continuous" or "all around."—"Machinery," November, 1933.

THE STELLA DUAL MAGNETIC COMPASS.

Since the unsteadiness of the ordinary form of dry-card compass renders it unsuitable for accurate steering, the liquid compass is generally employed for that work, although the liquid type of compass lacks the delicacy, sensitivity and lightness of the dry-card instrument. Recently, however, a new type of compass has been designed by Mr. N. C. Baird, and this instrument, it is claimed, while retaining all the advantages of the large-diameter dry-card compass, is not less steady than the liquid type. This compass, known as the Stella, is being made by Messrs. Stella Engineering Company, 38 Bath Street, Glasgow.

A photograph of the inner vessel is reproduced in Figure 1, but it should be explained that the vessel is here standing on one edge in order to render the card more easily visible. A section of the inner vessel is reproduced in Figure 2, while Figure 3 is a perspective drawing which will serve to make the principle of the instrument clear. Figure 4 is a section of the outer vessel in which the inner vessel is suspended on gimbals formed by two pairs of knife edges at right angles, so that the inner vessel always remains horizontal if the outer vessel is tilted. The latter, it should be explained, is completely filled with a non-freezing liquid which serves to damp out any oscillations of the inner vessel, and the weight of the latter is adjusted, by means of a lead weight, to give critical buoyancy. In the inner vessel an annular dry card is suspended by four radial arms from a pivot mounted on a central cylindrical box, and four sets of four short magnetic needles are mounted on stirrups carried by the radial arms, as is most clearly shown in Figure 3. The magnets, however, are also shown in Figures 1 and 2. Neglecting, for the moment, the contents of the cylindrical box, above referred to, it will be seen that the annular card and its attached magnetic system, which move entirely in air, will set itself in the magnetic meridian, but it will also be obvious that unless means were taken to prevent it, the card would continue to oscillate about a mean position for an inconveniently long period.

The method of preventing this oscillation is particularly interesting and ingenious. Referring to Figure 3, it will be seen that the cylindrical box contains another magnetic system consisting of eight comparatively long needles mounted on a bar supported by a pivot from the bottom of the box so that they lie in the same plane as those of the dry card. The box is completely filled with non-freezing liquid, so that the movement of the magnetic system is highly damped. If now the compass is turned away from the magnetic meridian, the central magnetic system will turn back to the meridian comparatively slowly, but with almost dead-beat motion. The annular card will oscillate slightly about its mean position, but the oscillations are kept of small magnitude and are rapidly damped out by the interaction between the magnets suspended from the dry card and those enclosed in the central box. Figure 5 shows the effect of turning the compass through 180 degrees, so that the north-seeking ends of the magnets were turned to the south. From the diagram it will be seen that the card came completely to rest in the right direction in a little less than 50 seconds, after making four oscillations. It may be mentioned that in this experiment the paper annulus on which the points are marked, the weight of which is 10.5 grains, was not in place. Actually the total weight of the dry card and its magnetic system is only 60 grains, as compared with about 200 grains which is the weight of the moving system in ordinary dry-card compasses.

Among other advantages claimed for the new system is that disturbance from outside magnetic influences is reduced, it is highly sensitive and is not subject to errors arising from friction, and the card is free from disturbance arising from vibration and mechanical shocks.—"Engineering," October 27, 1933.

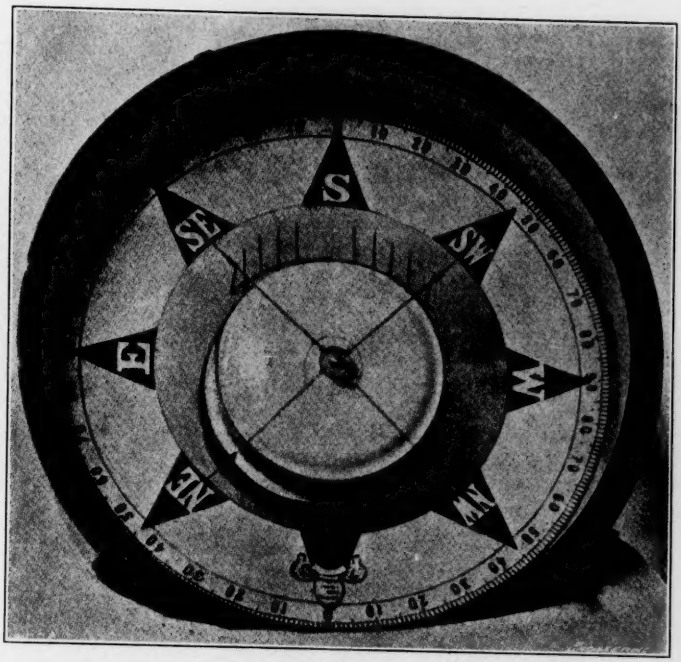


Fig. 1.

Fig.2.

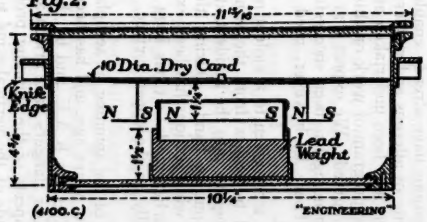


Fig.3.

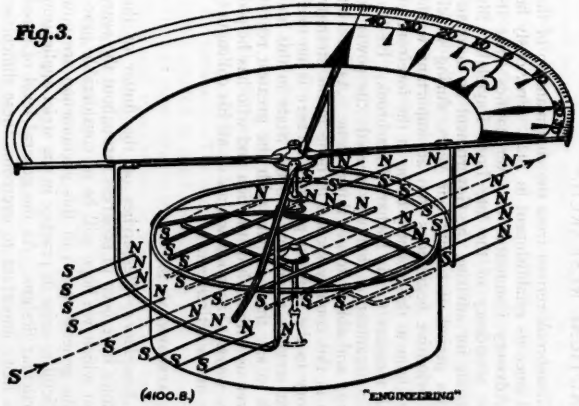


Fig.4.

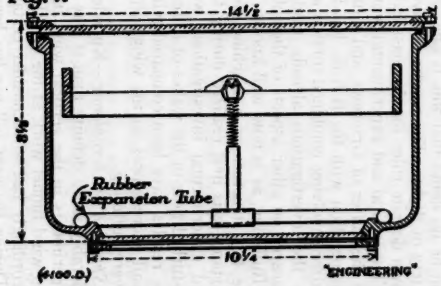
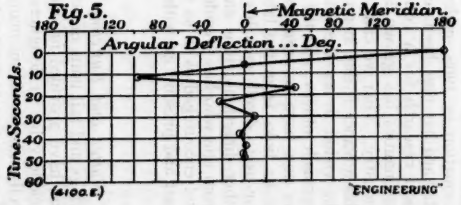


Fig.5.



AERONAUTICAL RESEARCH.*

In April last Sir Richard Glazebrook retired from the chairmanship of the Committee which he had held since its establishment in 1920. Previously he had been Chairman of the Advisory Committee for Aeronautics since its formation in 1909, under the presidency of the late Lord Rayleigh. Sir Richard has thus been responsible for advising the Government on aeronautical research for a continuous period of twenty-four years, during which aeronautics has grown from primitive beginnings into an important world industry. That we can justly claim in this country to be in the forefront of this advance is due in no small measure to Sir Richard Glazebrook. He had the vision to see the scientific organization that was needed; the power to persuade others; and the energy and ability to get things done. As a result we now have an organization in this country second to none in the strength of its links from the laboratory to the finished product. There is no need for us to dwell upon his great services to science and the State in this and other directions; it is enough to say that we part with the greatest regret from one who has presided over us with such distinction and who has helped and encouraged us in so many ways. The good wishes of all his colleagues, past and present, go with him in his retirement.

AERODYNAMICS.

Flutter and Buffeting of Aeroplanes.—Researches on the flutter of the wings and tail units of aeroplanes have been in progress throughout the year, and have provided information which we hope will be of considerable practicable value to designers. The general causes of this phenomenon are now well understood, but many difficulties arise in practice in the strict application of preventive measures to particular designs. As the general level of speed of aeroplanes rises it becomes more important to overcome these difficulties and therefore a good deal of further detailed work will be necessary. There can be no doubt that this is one of the most important factors affecting the safety of flight. The results of investigations have already enabled us to lay down definite rules for the mass balancing of ailerons and rudders.

Theoretical and experimental work has also been undertaken at the N.P.L. on the flutter of airscrews, and a further program of work on this subject, in co-operation with the R.A.E., has been agreed. We expect that the type of flutter involving combined torsion and bending has been successfully covered by the investigations already made. There is, however, need for further research on other aspects of the subject.

Buffeting, as is now well known, is a term given to a violent movement of the tail structure of a machine caused by eddies from the wing. Its importance was first realized during the inquiry into the accident at Meopham, and experimental investigations were put in hand. During the year the disturbed flow in the wakes of different wing sections has been examined and the results have been compared with earlier work. It has been shown that small excrescences on the wing, especially on the upper surface, may induce severe buffeting.

Spinning of Aeroplanes.—Knowledge of the spinning of aeroplanes is considerably more definite than it was a few years ago, and has been helped by experiments in the vertical wind tunnel at the R.A.E. and by the analytical and wind tunnel work at the N.P.L. New dangers have arisen and we have accordingly had to reconsider certain aspects of the spinning problem.

During the year full use has been made of the vertical wind tunnel at the

*From the Report for the year 1932-33 of the Aeronautical Research Committee.

R.A.E. An outcome of this line of inquiry is the discovery that the slots of slotted wings may cause difficulties in a flat spin. A "family" of model aircraft has been chosen for tests in this tunnel, in which the effect of varying one property at a time will be investigated. In the first series of experiments the wing position and arrangement will be varied for monoplanes and biplanes, using a standard body and tail. Concurrently with this investigation a systematic research on the effect of different shapes of body and tail will be begun in the horizontal tunnels at the N.P.L. Some of these body-fin combinations will afterwards form the basis of tests in the vertical spinning tunnel, using standard wings and different tail arrangements.

Stability and Control at and above Stall.—It is reported by pilots that some unslotted aeroplanes are more satisfactory than others in respect of stability and control at angles in the neighborhood of the stall. The reasons for the reported differences are not altogether clear, and we consider that there is still need for both full-scale and model experiments to determine on the one hand the nature of the differences in behavior which give rise to these diverse reports, and on the other hand the particular features of the aeroplanes to which the differences are due. Research on these matters is proceeding, but has not yet advanced far enough for a general report to be issued.

Performance.—The development of means for visualizing the air flow past models erected in wind tunnels and past the surfaces of aeroplanes in flight will be of considerable interest to designers of aircraft. We have therefore encouraged experiments in this direction. In 1928, Flight-Lieut. J. A. G. Haslam, working under Professor B. M. Jones at Cambridge University, successfully developed a method whereby wool tufts were attached to the surface of an aeroplane's wing and their behavior was watched during flight. When the air flow is steady the tufts lie along the wing surface, but when it is turbulen, they either wave violently about or even point forward, thus showing the regions where the flow near the wing surface is reversed. Professor Jones and Flight-Lieut. Haslam have continued the work and have published during the past year a further report describing a study of air flow over the wings and tail during stalled flight and spinning. These and other methods of rendering air flow visible in a wind tunnel have been the subject of experiments at the R.A.E. and N.P.L., and a recent report by the R.A.E. suggests that tufts provide most information and are simplest and quickest to use. We wish to take the opportunity of directing the attention of designers to these simple methods. This investigation is being further developed both by the R.A.E. and by Professor Jones, with whom the Cambridge University Air Squadron at Duxford Aerodrome is co-operating.

Airscrews.—A great deal of research on airscrews having high tip speeds has been carried out in recent years at the R.A.E. When the tip speed approaches the velocity of sound the efficiency usually decreases, and we consider that sufficient evidence has now been accumulated regarding the magnitude of this effect, for an account of the whole subject is to be prepared. Owing to the limitations imposed by tunnel speed, tests have hitherto been made only with fine pitch airscrews, but now that the high-speed tunnel at the R.A.E. is available the work is to be extended by tests on higher pitch airscrews. A report will shortly be published summarizing the work so far carried out. Attention has been drawn to the desirability of limiting the thickness of the blade section at the tip, but it would appear that an important objection to the thin section is its small maximum lift coefficient.

With improved performance airscrews are now being used with higher pitch/diameter ratios, especially on racing aeroplanes and high-speed aircraft for the Royal Air Force. A research on this subject has been commenced at the N.P.L. in order to obtain data on airscrews whose pitch/diameter ratio extends up to a value of 2.5.

Landing and Take-off Characteristics of Aircraft.—We have been interested in a question raised by the Society of British Aircraft Constructors as to why some aircraft appear to float a considerable distance just clear of the ground before touching, while others seem to alight in a very much shorter distance after flattening out. After a discussion the conclusion was reached that there is nothing in these differences of behavior which cannot be explained by existing theory and from a knowledge of the aero-dynamic characterstics of the machine. The whole question of safe and easy landing requires, however, further attention, and we are considering proposals for a comprehensive investigation.

The Director of Scientific Research, Air Ministry, has communicated a report by an Air Force Officer on his experiences during the R.A.F. South African flight, 1931, which indicated that, in certain circumstances, a heavily loaded aeroplane, although able to take off, experienced difficulty in climbing from a few feet above the ground to a height of 200–300 feet. Above this height the rate of climb became normal again. In discussion Dr. Simpson referred to the very rapid fall of temperature with height in Ismailia, and the Committee has asked for a number of experimental flights to be made through this unstable atmosphere to determine whether it has any marked effect on performance.

Autogiros.—We welcomed an opportunity last year to see at Farnborough an early flight trial of the new experimental wingless autogiro developed by Señor de la Cierva. This machine is a great advance on previous designs; the control is now independent of forward speed, with the result that both the vertical descent and take-off are greatly improved and a more powerful control on the ground is provided. The longitudinal and lateral control are effected entirely by operating the axis of the rotor, which is tilted fore and aft or sideways. Recently the Committee has had an opportunity to discuss developments with Señor de la Cierva.

We are keeping in touch with the progress of the new autogiro (of the wingless type) that is being built to Air Ministry order, and are examining certain problems of its stability and control.

Fluid Motion.—Examination of the details of turbulent flow—by the ultra-microscope, by smoke (titanium tetrachloride), and by photographing the shadows thrown by heated air—has been continued at the N.P.L. during the year, and light has been thrown on several questions which had formerly been in doubt.

Many theoretical papers have been received during the year, both from official and from independent sources. The problems considered have included the transmission of heat from hot bodies to fluid streaming past them, the flow of viscous and inviscid fluids past obstacles of various shapes, the stability of certain types of fluid motion, and the flow past aerofoils at speeds above that of sound.

ENGINES.

It was pointed out in last year's report that the production of still lighter petrol engines now depended mainly on improvements in detail, but that much remained to be done in promoting fuel economy, especially under cruising conditions. Following the development at the R.A.E. of a device for the automatic control of fuel-air mixtures, recent investigations have provided results of outstanding interest. It has been shown that it is possible to reduce fuel consumption at the reduced power required for cruising to a figure very substantially below anything attained in flight hitherto. This work is being actively pursued with a view to the reproduction in flight of results obtained on the test bed. Successful development along these lines should be of considerable interest to civil air transport.

Research on heavily supercharged single-cylinder units has been continued. In the case of petrol engines it has been shown that the indicated power increases practically proportionally to the degree of supercharge up to initial pressures as high as three times the normal pressure. It has been found, however, that whereas at ordinary pressures it is possible to get satisfactory combustion of weak mixtures of petrol and air, the effect of supercharging is to narrow the practical range of mixture strength. Apart, therefore, from the loss of economy to be expected in a supercharged engine by reason of the necessary lowering of compression ratio, and from having to drive its own supercharger, it appears that definite limitations to the degree of supercharging in practice may be imposed by difficulties of combustion rather than by mechanical considerations.

When compression-ignition engines are supercharged the indicated power does not increase in proportion with the initial pressure. Theoretical investigations indicate that this difficulty is not likely to be overcome by improvements in design, and therefore that the production of light compression-ignition engines will not be facilitated by heavy supercharging. A moderate degree of supercharging has, however, many advantages. As we stated in last year's report, we consider that the development of the two-stroke compression-ignition engine holds out the greatest promise of success in the production of a satisfactory power unit sufficiently light to compete with the petrol engine.

At present, research is proceeding at the works of Messrs. Ricardo and Co. upon a sleeve valve unit, and we are informed that there is a likelihood of the construction in this country of an alternative type of two-stroke engine in which two pistons are employed per cylinder. At the same time development is proceeding normally on various types of four-stroke engine, and with these valuable practical experience is being accumulated.

Lubrication.—In our last report we referred to the setting up of a panel of the Engine Sub-Committee to study problems of lubrication of aircraft engines. This panel has now made a general survey of the present position, and has issued a preliminary report. An extensive series of investigations has been started, including a study of the oxidation of lubricating oils and of the methods by which oxidation can be retarded; experiments on these lines are being made both in the laboratory and in the engine. A search for suitable gum solvents is in progress with a view to the early removal of the gummy deposits from the pistons if their formation cannot be prevented.

The stability of oils tends to decrease with increase of viscosity, and the extent to which it is possible in practice to use low viscosity oils is being determined by engine tests. Lowering the viscosity tends to increase the oil consumption, *i.e.*, the passage of oil past the piston, and the panel is putting in hand experiments to determine the nature of the action of the piston rings in promoting the passage of oil past the piston.

The problem before the panel is complicated, and some time is likely to elapse before their final report is issued.

Engine Power at Heights.—The problem of the variation of engine power with height has been under investigation for many years. So far as the unsupercharged engine is concerned, the reduction factor proposed has varied from one dependent solely on density to one dependent solely on pressure.

The early Martlesham Heath experiments on the power law for the supercharged engine appeared to indicate a density basis for fully supercharged engines and a pressure basis for moderately supercharged engines. A recent re-investigation has not confirmed the previous results for supercharged engines nor the disparity between moderately and fully supercharged types, but the results agree with the conclusion adopted some years ago by the

N.A.C.A. for normally aspirated engines, namely, that the power varies as the square root of the product of pressure and density. It must be remembered that this is an approximate rule and does not necessarily apply to a particular engine.

Fuels.—During the year we have reviewed the present position of the supply of volatile fuels for aircraft engines. Clearly the most suitable fuel is that which has the highest possible content of available energy per unit weight, and which can be used with the highest thermal efficiency that mechanical considerations allow; but practice demands the use of fuels which are readily available all over the world at a reasonable cost. The idea still seems prevalent in some quarters that there may some day be brought into use a liquid fuel with a substantially higher content of available energy of combustion per unit weight than the hydrocarbon fuels now available. This we may say definitely is unlikely. On the other hand, available hydrocarbon fuels are not at present used with the efficiency that should be possible; it is the fuel that sets a limit to the achievements of designers of petrol engines. the use of dopes, such as tetra-ethyl lead, goes far to remove this difficulty, but introduces other difficulties in practice: these are gradually yielding to continuous investigation in this and other countries. It is not, however, out of the question that a synthetic fuel may be produced which, though it may have no greater or even less available energy per unit weight than petrol, may yet have properties which permit of a higher thermal efficiency in practice. We shall explore any such possibility.

Flame Traps.—During recent years a satisfactory form of flame trap has been developed at the R.A.E. to prevent back-fires from the engine sending flames down the induction pipes. These flame traps are made of thin sheet metal which divides the pipe into a large number of passages sufficiently small to cool and damp out any flame traveling along the pipe. The traps have stood up to long periods of artificial back-firing under test bench conditions, and have also been flown for a number of hours in the air without any sign of failure. In view of these successful tests the Accidents Sub-Committee has amended its recommendation, made some years ago, that, on account of the risk of fire, air intakes should preferably be placed outside the fuselage of an aeroplane; it now suggests that with a satisfactory flame trap the intakes may safely be placed inside the fuselage. There are clearly other advantages resulting from the adoption of internal air intakes, for example, the absence of choking in snow or sand storms, and it has been noted that general carburation is improved, with the result of smoother running of the engine, when a flame trap is fitted.

STRUCTURES.

Thin Sheet Metal.—In view of the use of thin metal sheet for construction work on aircraft, the types of failure of panels of sheet metal are being investigated. The Bristol Aeroplane Company, Ltd., has collaborated in the work of designing and testing a large cylindrical test specimen. Special specimens have also been prepared and tested at the R.A.E. to supplement and extend the work of this company.

The main object of the work at the N.P.L. is the development of reliable theoretical methods for the determination of the strength of structures built up from thin sheet metal. In the first instance some experiments are being made on the collapse (as distinct from the buckling) of rectangular thin sheets, of which all four edges are clamped, under compression parallel to one pair of opposite edges. Similar tests on rectangular thin sheets of which all four edges are simply supported have been carried out in America; the purpose of the N.P.L. tests is to determine whether the approximate theo-

retical analysis that has been applied with some success to the results of the American work can be adapted to the more practicable case of the panel with all four edges clamped. As a result of these tests it is hoped to determine the critical strain that such panels will support without collapse, and it is considered that if the stiffeners are then designed to support the same critical strain without buckling, the behavior of the stiffened construction will be determinable.

Torsion of Metal Tubes.—The strength of steel tubes in torsion has been investigated by Professor Andrew Robertson and Mr. Newport, of Bristol University. Tests were carried out on drawn mild steel tubes and on solid drawn tubes.

By their mode of failure the tubes can be divided into three classes, namely, thick tubes that first yield and then fail by shearing; thin tubes that fail by elastic instability, their strength depending upon the elastic properties and not upon the strength properties of the material; and tubes of intermediate thickness that first sustain the shear yield stress of the material, and afterwards collapse by the formation of wrinkles in the walls of the tube at stresses which vary with the ratio of the thickness to the diameter. It was found that the stress at which yielding occurred was not independent of this ratio. This work has produced results of considerable interest to aircraft constructors.

Up to the present time no satisfactory theoretical analysis of the stability of thin-walled tubes in torsion has been published. The problem has been considered by Japanese and German workers; but since their analyses are based on the theory of thin shells, which is open to objection as applied to the problem of a tube in torsion, the results must be regarded as inconclusive. This view is supported by the fact that the results of the two analyses do not agree either with each other or with the results of the tests carried out by Professor Robertson and Mr. Newport. The development of a satisfactory theory is therefore thought to be a matter of considerable importance.

Aeroplane Spars.—Considerable progress has been made with a lengthy series of tests on seven aeroplane spars kindly supplied by aircraft firms, to discover whether existing methods of test for strength and stiffness are satisfactory, and how they can be correlated with tests on the strip material from which the spars are constructed and for which various new types of tests are being devised and tried out. It has been proposed that the present tests be replaced by tests (*a*) on a short length of spar under slightly eccentric end load, (*b*) on a longer length of specimen to determine the variation of the elastic constants, and (*c*) to destruction on the test piece used in (*b*). These proposals are being borne in mind, but the Structure Sub-Committee is not at the present time in a position to recommend any change.

ACCIDENTS.

The Accidents Investigation Sub-Committee is investigating a series of accidents involving structural failures in the air of the Puss-Moth. It is not yet in a position to issue a report.

MATERIALS.

Fatigue.—The influence of the atmosphere upon the fatigue strength of metals has been investigated at the N.P.L. Comparative tests on the fatigue of representative aircraft materials were made in air, with and without a coating of lanoline grease, and in vacuo. As a further investigation of this effect tests under alternating direct stresses were carried out on more uniform research materials; these showed that, when tested under very low

pressures in the absence of air, the fatigue strength of a mild steel was increased by 5 per cent, of annealed brass by 26 per cent, and of annealed copper by 13 per cent. Similar tests made in air on specimens coated with lanoline showed that the effect of the coating was not protective, the fatigue strengths being slightly lower in tests on uncoated specimens. The very considerable increase in resistance to fatigue exhibited in the tests in vacuo make it apparent that, in normal tests in air, atmospheric corrosion may play an important part; but it is not yet decided whether this corrosion is to be attributed entirely to the oxygen or whether water vapor, acting either independently or as a catalytic agent, is essential to the process.

Welded Joints.—We have considered some problems of welding brought to our attention by the Society of British Aircraft Constructors and makers of aluminium alloys. Although sound welds in heat-treated alloys can now be made without difficulty, the material in the immediate neighborhood of the weld necessarily loses the properties due to heat treatment, and to restore its full strength subsequent heat treatment and cold work, or, in come cases, cold work alone, would be required. In the case of aircraft structures neither of these operations would as a rule be practicable after welding, and therefore the use of welding commonly involves considerable reduction of the strength of high-tensile alloys.

We are taking steps to collect available information on this subject from aircraft constructors and elsewhere in order to decide whether any scientific investigations would be helpful.

Magnesium Alloys.—Several papers have been received from the R.A.E. on methods of protection of magnesium alloys against corrosion.

ATMOSPHERIC TURBULENCE.

In order to record the intensity of the accelerations to which aircraft are exposed when flying in bumpy weather, a number of flights have been made from Farnborough of aeroplanes fitted with recording accelerometers. Flights have been made on four types of aircraft whenever gusty weather was expected; the results obtained are of considerable interest and value, and we wish to record our appreciation of the work carried out by the pilots, for the records show that the conditions must frequently have been extremely unpleasant. The maximum accelerometer readings recorded normal to the flight path were 2.8 grams and —0.6 grams respectively. Although flights were made on every occasion of high winds, the year was unusually free from really bad weather, and it is felt that further observations should be made during gales. Flights will, therefore, continue to be made at Farnborough when it is anticipated that the gradient wind will exceed 30 miles per hour, unless the conditions are such as to render flying dangerous, *e.g.*, in the near neighborhood of thunderclouds and line squalls.

We think it important to collect statistical information by fitting accelerometers to aircraft, both service and civil, which are carrying out routine flights, in order to obtain records over long periods of time. It is considered that from such records valuable information will be obtained regarding the stresses likely to be imposed on aircraft structures by gusts.

NOISE.

A paper on the silencing of aircraft has been written by Dr. A. H. Davis in a form intended to be suitable for the use of aircraft designers. It gives figures for the loudness levels of various noises that occur in houses, in streets, and in different vehicles, and for the noise levels of airscrews, of exhausts and of engine clatter. Reference is made to the insulating value of various types of cabin wall, and to the importance of locating the power

plant in some favorable position. Results of noise measurements made in various types of commercial air liner are presented and analyzed. A tentative table is given from which it is possible to assess the order of loudness of the noise in the cabin of a machine, provided the situation of the engine, of the exhaust and of the airscrew are known, in addition to data concerning the tip speed of the airscrew and the structure of the cabin walls. The analysis proves to be in general accord with the results of experiments which have been carried out on testing plant. This paper has been circulated to members of the aircraft industry.

Interesting results have been obtained from experiments on exhaust silencers manufactured by Rolls Royce, Ltd. On the test bench the silencer was shown to be capable of reducing exhaust noise by a very large amount, but on the aeroplane the total noise level is not reduced by this amount, because after a certain reduction the airscrew noise predominates. Different types of engine cowling had no effect on the noise levels, so that engine clatter was not in this instance of importance. The conclusion reached is that unless airscrew noise can be substantially reduced it is not of importance to proceed to extreme limits in silencing the engine exhaust.—"The Engineer," Sept. 1, 1933.

NAVAL TRAINING.

A General Review.

By "Observer."

The Navy is certainly one of those human institutions which, as Admiral Richmond says in his introduction to a recent publication,* "require watching, for conditions change, experience develops, new needs arise"; and from time to time it is essential that the system of naval training as a whole, as well as the details of instruction, should be surveyed in the light of new requirements. This, unfortunately, was not always done, and at a time when ships were becoming more and more mechanized, the training of officers and men was still based on conditions as they existed in the days of masts and sails. Many of us who received our first professional instruction in the old *Britannia* will recall that, on going to sea, we were singularly ill-equipped to perform the duties even of a subordinate officer. We spent many months learning the mysteries of "standing and running rigging"; "making and shortening sail"; "tacking and wearing a full-rigged ship"; we sat by the hour, robed in canvas aprons, making "long splices," "short splices," and "Matthew Walker knots," concealing their defects by a plentiful use of tallow and much rolling under foot; and we learned all manner of old-time orders, such as "raise tacks and sheets"; "very well thus—keep her as she goes"; or "watch there, watch!" But, when we stepped on board our first sea-going ship, we found that "come on board to join, sir" was one of the few phrases which we had been taught which had a modern application. We knew nothing of a battleship's routine—which it was one of our first duties as midshipmen to see carried out punctually; we had been taught little or nothing of the nomenclature of a modern ship; we were put in charge of a gun, but gun drill was a foreign language and gun mechanism a hidden science; the evolution of getting out nets, which at that time stirred the whole ship's company to its vitals at least once a week, was mere mean-

* "Naval Training," by Admiral Sir H. W. Richmond, Oxford University Press.

ingless pandemonium to us, for although there was an admirable model of a net defence in the *Britannia's* seamanship room, it was never explained because it was no part of the curriculum.

In 1902, under the inspiration of Fisher, drastic changes were made in the system of entry and training of naval cadets. The Osborne scheme, as it was called, has been roundly abused and, in the course of thirty years, it has undergone considerable modification—its enemies would call it complete extinction. But it marked a vital change in the education of the naval officer, one which was long overdue and which has endured ever since. That change was the introduction of systematic mechanical training from earliest days.

Admiral Richmond, in a chapter entitled "The Place of Engineering,"* criticises the extent to which the naval officer of today is trained as an engineer. "Nowadays," he says, "the captain on the bridge can turn his ship, cast her, handle her, judge how hard he can drive her into a sea without in any sense whatever being an engineer." Perhaps he has forgotten the classic instance of the spirited young captain, brought up in the old school, who against the advice and, eventually, the entreaties of his chief engineer, drove his cruiser to a complete standstill and did thousands of pounds damage to her engines because he thought a hot bearing could be ignored. Again, the author argues that while the officer of a turret needs the "practical knowledge of the driver of a machine," he does not require to know "how the machinery is constructed or the scientific laws of design . . . nor is it necessary for the military officer to be able to repair the machinery." But this ignores such matters as upkeep, breakdowns in action, and replacements by spare parts—a knowledge of which is essential to a turret officer, unless he is to be entirely in the hands of his subordinates when the slightest emergency arises.

To argue that a naval officer only needs to know how to handle his ship, his guns or his torpedoes, and not to understand the principles and parts of the machinery which moves them, and how to maintain that machinery and get the best out of it, is like saying that even an experienced and reliable motorist should never look inside the bonnet of his car, and should leave all its mechanism to the garage mechanic or his chauffeur, if he has one. Splicing a rope or wire is still regarded as an essential part of an officer's qualifications as a "seaman"; but it is asserted that a knowledge of "how glands are packed" does not affect him as a "strategist or tactician." Yet the fighting efficiency of a modern ship is far more likely to be reduced by a defective joint than by a drawn splice.

The fact is that a system which would make the practical knowledge of machinery the business of a specialist class of officers and men is as unsuitable today as the system which at one time confined the practice of navigation to a specialist branch. To deny the military branch of naval officers a proper mechanical training is to fail to equip them in what has become one of the essential qualifications for command in all its various grades.

The firm establishment of this principle does not, however, preclude periodical examination of other aspects of naval training, such as age of entry, preliminary education, professional specialization, and the attributes necessary for higher command. But, when criticising the existing order of things it is essential that they should be described correctly, and this, unfortunately, Admiral Richmond does not always do. For instance, after showing somewhat of a predilection for a classical education, he says "In the service we have gone to the opposite extremes and attempted specialization with little boys whose minds are too immature to absorb the knowledge.

* "Naval Training," Chapter III, p. 14.

We have endeavored to instil knowledge, in fact, into receptacles which have not been rendered fit to receive it." It is arguable whether minds cannot be prepared for greater knowledge by the gradual absorption of subjects which will be of practical value just as effectively as they may be fertilized by a preliminary education which is largely academic. But, in point of fact, the education at Dartmouth College is not specialized to a great extent, and the board of education inspectors have stated that the curriculum does not differ markedly from one which might be followed by boys in a public school. Admiral Richmond also complains that "no attempt is made to differentiate the subjects of instruction according to natural aptitudes," but perhaps he is not aware of what is called the "Alpha class scheme" at Dartmouth, which is designed to fulfill this very object. In naval training, there must, of course, be a limit to the facilities given to the individual to follow his special bents; if he desires to pursue studies outside that limit it can only mean that he has chosen the wrong profession.

No one will dispute the importance of history and of English—especially the latter—as part of the preparatory education for a naval officer, and it is understood that particular attention is paid to these subjects at Dartmouth, but history cannot be regarded as more important than mathematics in early training. It is a good thing that a boy should be inspired by reading of heroic deeds and great adventures, and that he should be encouraged to read history more and more as he grows older; but it is very doubtful whether any youth in his teens can study history in that analytical spirit which makes it of special value to training for higher command. Mathematics, on the other hand, is the A.B.C. of professional education—of navigation, pilotage, maneuvering ships in company, handling weights, the elementary principles embodied in every type of machine, electricity, and a hundred other subjects which are inseparable from the naval officer's daily duties afloat. It must not be forgotten that the cadet requires all his application and energy directed into the right channels to make him an efficient lieutenant, and at that early age it would be a great mistake to make him "specialize" in a course of training designed to make him a great admiral.

If the present system had the defects of the old *Britannia régime*, there would be more point in Admiral Richmond's implied criticism that cadets are not taught officers' duties; but the re-introduction of the training cruiser should go far to make good this defect. In the "Frobisher," besides gaining elementary practical experience in seamanship, gunnery, torpedo, navigation and engineering, cadets are initiated into ship life, ship routine and midshipmen's duties as they cannot be in a college on shore. But no amount of "instruction" can make an officer; he must be put in a position where he is regarded as an officer, and given, increasingly, the responsibilities of an officer, if he is to become efficient. The extent to which that is done must always depend to a greater or less extent on his seniors and particularly on the captain and executive officer of the ship in which he is serving. Undoubtedly, the smaller the ship the greater the share of responsibility which can be given to the young officer, and the arrangement whereby midshipmen do three to four months in destroyers, and some are appointed to "D" class cruisers, has everything to recommend it. Yet, from time immemorial, the majority of youngsters—whether officers or men—have undergone most of their early sea-going training in the big ship where there are better facilities and more seniors to look after them.

Admiral Richmond inveighs against the "bugbear . . . of the recurring examination," * but, human nature being what it is, there can be no doubt that examinations are necessary in order to apply that fear of failure which

* "Naval Training," p. 96.

will ensure application to study by the less ambitious, while giving opportunity to those who work hard or are specially gifted to come to the front. On the other hand, when it comes to promotion, advancement by competition in the written examination requires to be severely tempered by proof of other officer-like qualities. The ranks of the "Five Oners"* have produced some of the best officers in the Navy, but they have also produced some of the worst. It is on this very subject that many people will join issue with Admiral Richmond when he proposes that entrance to the service should be by competitive examination and that "initial selection must be made in such a manner that we can throw the net as widely as possible and catch in it all who are, or have in them the promise of becoming educated persons."† This seems to leave out character—not the character that may be acquired by education, but the character with which the boy who is likely to make a good officer is endowed by birth, early environment and his own inherent qualities. It is the exception that the secondary school boy can present himself for the navy already possessed of these essential characteristics, and it is only the exceptional boy who, starting without them, will acquire them as the result of naval training. Even under the existing special entry scheme some misfits get in and have to be removed before completing their time as cadets. There is no doubt that the "interview" system of preliminary selection is for the good of the service, and does much to prevent the entry of misfits and subsequent wasted training. It is the most difficult problem in making promotions from the lower deck to commissioned rank to ensure that the men selected are not merely clever examinees of good appearance and educational standards, but that they really possess those essential quaiifications of an officer which give ability to command.

The idea that head masters should be regarded as judges of officer-like qualities in a boy, presupposes that they all have the same, and a correct, outlook on the subject: which is far from being the case.

Admiral Richmond would enter boys at the age of 16-18, give then a professional course at a naval college for a year and a half, send them to sea as midshipmen or sub-lieutenants for two years, during which they would do no instruction. If recommended by their captain, but without further examinations, they would then be promoted to lieutenants. After two more years at sea they would do a war course lasting a year, at the end of which officers would be selected for the specialist branches.

This would mean that professional *instruction*—as distinct from experience—up to the time of promotion to lieutenant would be limited to the eighteen months at the college, as compared to (*a*) the three years at Dartmouth when professional instruction is combined with general education; (*b*) the instruction in the training cruiser; (*c*) instruction during midshipmen's service in big ships; and (*d*) sub-lieutenants' courses. Experience with the special entry has shown that boys coming straight from school have not had the necessary grounding in mathematics to enable them to proceed forthwith to the study of navigation, while technical courses as sub-lieutenants are essential to equip an officer for lieutenant's duties. Apart from this, it has been found very desirable that there should be a break in the always exacting, and sometimes monotonous, life afloat at about the age when, in shore life, a young man would be going to the university to fit himself for whatever career he had selected.

Sub-lieutenants already do a short war course, and a lieutenant of two years seniority would not have had sufficient experience to benefit by a war

* Officers who secured five first-class certificates in their examinations for the rank of Lieutenant, R.N.

† *Ibid*, p. 24.

course lasting a whole year. The higher study of war cannot be undertaken profitably until the student has learned the technique of his profession and the practical aspects of staff work. Undoubtedly, it would be an advantage if all lieutenants could be given a course in staff work, i.e., in appreciating situations, writing orders, making plans for operations, etc., but a course for the higher study of war should come—as it now does in the navy—when officers have had experience in command or at least as second-in-command, and, preferably, when they have a practical knowledge of staff work.

There is one most important omission in Admiral Richmond's proposed curriculum, and that is any provision for training in flying and for acquiring experience in naval air work generally. This has not been overlooked by the authorities and now forms an indispensable part of naval training.

The general impression left by this book is that many of the criticisms would have been justified several years ago, but do not really apply today. Others, while admittedly sound, cannot be met as easily as the author implies. He deplores the changes of 1902 as not being the outcome of any committee's deliberations, and then proceeds to propose scarcely less far-reaching changes. Many of his proposals, it is understood, have been examined and rejected; others which seemed good in theory have been found impracticable. It must always be borne in mind that any sweeping changes may affect the service for a great many years before unforseen ill effects can be righted. A very thorough investigation of all officers' training was carried out recently, and it is noticeable that no change has been found necessary in the main principles. The chief alteration has been the revival of the training cruiser—the advantages of which seem indisputable.

The implication that the products of the system of naval training which has been in force during recent years are helpless and hopeless is far from being the experience of senior officers now serving. The young officer of today is much better equipped to perform his duties efficiently than he was thirty years ago. If there is anything lacking it is more opportunities for him to exercise responsibility and take initiative, and these should occupy the unceasing attention of commands afloat. Much could be done by reverting to the simple signal instead of the lengthy printed memorandum, whereby officers would have to work out details for themselves instead of being "spoon fed." Staff work should never swamp ship individuality. Flag officers should regard the captains of their ships as their advisers and the medium for giving effect to their orders and wishes, and at all times restrain their staffs from drafting or issuing unnecessary instructions. This will give captains far more scope than they possess at present for developing individuality of their officers. At an early stage in an officer's career it may be necessary that he should be trained to conform largely to the "sealed pattern," but the more senior he becomes the more scope he should be given for originality and initiative. Far too many officers get promoted because they have "conducted themselves to my entire satisfaction." There is an undue tendency, today, for those in the promotion zone to be ever on guard to do nothing unorthodox lest they should be conspicuous—to their own detriment. All training has two ends in view: the acquisition of knowledge and the development of character; but the latter, which is even more important than the former, is not dependent on training alone. It is the duty of higher authority to encourage officers to emerge from the "sealed pattern" state, to show originality, and not to be afraid to make themselves conspicuous, so long as their enthusiasm and enterprise are aimed at promoting the interests of the service.—"Journal Royal United Service Institution," August, 1933.

ASSOCIATION NOTES.

The Annual Meeting of the Society for 1933 was held at Washington, D. C., on Tuesday, October 3, 1933. The following were nominated for offices for the calendar year 1934:

For President:

Admiral William H. Standley, U. S. N.

For Secretary-Treasurer:

Commander H. B. Hird, U. S. N.
Commander C. S. Gillette, U. S. N.

For Member of Council:

Captain A. C. Stott, U. S. N.
Captain H. R. Greenlee, U. S. N.
Captain C. A. Jones, U. S. N.
Captain Henry Williams (CC), U. S. N.
Commander J. J. Broshek, U. S. N.
Commander Garland Fulton (CC), U. S. N.
Commander W. M. Prall, U. S. C. G.
Commander H. F. Johnson, U. S. C. G.
Lieut. Commander D. H. Clark, U. S. N.
Mr. A. E. F. Horn.
Mr. Roland Whitehurst.
Mr. John E. Burkhardt.

Polls will close at 4:30 P. M. December 26, 1933.

It was decided to hold a banquet in 1934. This event, which had been held annually until 1933, when it was omitted due to economic conditions, has always been a most delightful occasion, and has been considered the best possible opportunity for social contact between the naval and civilian personnel.

MEMBERSHIP.

The following members have joined the Society since the publication of the last previous JOURNAL.

NAVAL.

Cleave, Edwin C., Lieut., U. S. N. R., 8200 Ellis Ave., Chicago, Ill.

Hicks, R. L., Lieut. Commander, U. S. N.

Karapetoff, Vladimir, Lieut. Commander, U. S. N. R., 520 East Buffalo St., Ithaca, N. Y.

Kephart, R. C., Lieut., U. S. N.

Latrobe, William C., Lieut., U. S. N.

Miles, Milton E., Lieut., U. S. N.

Nuesse, Louis W., Lieut., U. S. N.

Small, Lisle F., Lieut. Commander, U. S. N.

Steinwachs, F. S., Commander, U. S. N.

Thomas, William D., Lieut. Commander, U. S. N.

Withers, Cleemann, Lieut., U. S. N. R., R. F. D. 2, Ridgewood, N. J.

ASSOCIATE.

Tann, Walter L., 3025 87th St., Jackson Heights, N. Y.